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WATER QUALITY ASSESSMENT OF SETTING LAKE, MANITOBA, CANADA

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Water Quality Assessment of Setting Lake, Manitoba, Canada

Summary

A water quality study of Setting Lake was conducted during the summer of 2000. The study focused on a cottage development area between Wabowden and Sasagiu Rapids.

On June 22, 2000 initial samples were collected at approximately near the surface and 1 m off the bottom at each of four sites. Water from these samples was analyzed for 83 variables including general chemistry, nutrients, fecal coliform bacteria, dissolved oxygen, major ions, heavy metals, pesticides, and others. Subsequently, volunteers collected six more sets of water samples within the euphotic zone between the beginning of July and mid-September 2000. Water from volunteer sampling was analyzed for phosphorus, various nitrogen compounds, fecal coliform bacteria, chlorophyll *a*, pH, conductivity, and turbidity. Trace metals and major ion analyses were also included in the first set of volunteer samples.

There were few excursions from water quality objectives. There was one minor excursion for total phosphorus and one minor excursion for iron. Twenty-five variables used to calculate the Canadian Water Quality Index (CWQI). The CWQI indicated that water quality in Setting Lake was excellent.

Évaluation de la qualité de l'eau du lac Setting (Manitoba, Canada)

Résumé

Au cours de l'été 2000, une étude de la qualité des eaux du lac Setting a été menée. L'étude a porté principalement sur une zone d'expansion de résidences secondaires entre Wabowden et les rapides Sasagiu.

Le 22 juin 2000, de premiers échantillons ont été prélevés à la surface de l'eau et à environ un mètre du fond dans quatre sites. L'eau de ces échantillons a été analysée en fonction de 83 paramètres, notamment les éléments chimiques de base, les substances nutritives, les coliformes fécaux, l'oxygène dissous, les principaux ions, les métaux lourds et les pesticides. Par la suite, des bénévoles ont recueilli six autres groupes d'échantillons d'eau dans les régions euphotiques entre le début de juillet et la mi-septembre 2000. Ces échantillons ont été analysés en fonction du phosphore, des divers produits azotés, des coliformes fécaux, de la chlorophylle-*a*, du pH, de la conductivité et de la turbidité. Des analyses de métaux-traces et d'ions principaux ont aussi été faites sur les premiers échantillons prélevés par des bénévoles.

On a constaté quelques écarts par rapport aux critères de qualité de l'eau. Les valeurs de phosphore total et de fer présentaient de légers écarts. On a utilisé 25 paramètres pour calculer l'index canadien de la qualité de l'eau. Ce calcul a révélé que la qualité de l'eau du lac Setting était excellente.

Water Quality Assessment of Setting Lake, Manitoba, Canada

BACKGROUND

Setting Lake (54° 59' 58" N, 98° 37' 18" W) is part the Grass River system and is located near Wabowden, Manitoba. The lake is long and relatively narrow. It is accessible at several locations off PTH 6 between Wabowden and the outflow at Sasagiu Rapids (Figure 1). Setting Lake has a surface area of 13427 ha and a mean depth 5.8 m (Macdonald 2000). Bed rock is mainly metasedementary rocks including gneiss and magmatite derived from arkose, arenite, quartzite, and minor greywackle and conglomerate (Weir 1983). There is also granite and granitoid gneiss, and mafic intermediate metavolcanic rocks, and amphibolite. Surficial deposits are mainly deep basin deposits of silt, clay and sand forming extensive lake plains and a discontinuous veneer reflecting the form of the underlying topography. There are areas of extensive iceberg scouring; areas masked by thin alluvium and areas of wave washed till and exposed bedrock. Soils are mainly Gray Luvisol with some Organic Fibrisol and Mesisol and Organic Cryosol. The surrounding vegetation is mainly northern coniferous forest.

This report describes water quality of Setting Lake in the vicinity of the major cottage development area located between Wabowden and Sasagiu Rapids (Figure 1).

METHODS

Four water quality sampling sites were located on Setting Lake. Sites WQ0599 and WQ2282 are located in the main body of Setting Lake upstream and downstream of the cottage development (Figure 1). Site WQ02286 is located within a relatively small bay to the east of the main lake. This bay has a considerable number of cottages located on the eastern and northern portions of its shoreline. Site WQ02287 is located south of a small narrows in an undeveloped portion of the bay where it opens up toward the main body of Setting Lake. On June 22, 2000 initial samples were collected at approximately 10 cm below the surface and 1 m off the bottom at each site. Water from these samples was analyzed for 100 variables including general chemistry, nutrients, fecal coliform bacteria, dissolved oxygen, major ions, heavy metals, pesticides, and others.

Subsequently, volunteers collected six more sets of water samples near the surface between the beginning of July and mid-September 2000. Water from the volunteer sampling was analyzed for phosphorus, various nitrogen compounds, fecal coliform bacteria, chlorophyll *a*, as well as pH, conductivity, and turbidity. Trace metals and major ion analyses were also included in the first set of volunteer samples. Volunteer sampling procedure during the summer included measuring the Secchi disk depth. The Secchi disk is a 20 cm diameter black and white disk that is lowered into the water to a point where it disappears from sight and the depth that this occurs is recorded. Samples were collected where possible throughout the water column to a depth of twice the Secchi disk depth. A depth of twice the Secchi disk depth is the approximate depth of the euphotic zone, or zone of light penetration where algal photosynthesis can occur. Volunteers also recorded water temperatures.

Data collected over the summer of 2000 were compared using Student's "t" tests. A Student's paired "t" test ($\alpha = 0.05$) was used to test for differences in concentrations between each water sampling site on Setting Lake. With the exception of pH, all data was transformed to a log base prior to statistical analysis in order to stabilize variances. The average monthly Secchi disc transparency and chlorophyll *a*

from 1981, 1982, 1983, and 2000 were compared using the same method.

Water Quality Index

Water quality is typically assessed by measuring a large number of variables, including bacteria, plant nutrients, major ions, trace metals, industrial organics, agricultural pesticides and many others. The Canada Water Quality Index (CWQI) was used to describe the overall quality of water in Setting Lake (CCME 2000). Some 25 variables were compared with water quality guidelines and objectives (Williamson 1988, 2001) to calculate the CWQI.

The CWQI mathematically incorporates information on water quality from three factors. The basic premise of the index is that water quality is excellent when all water quality guidelines or objectives set to protect water uses are met virtually all the time. When guidelines or objectives are not met, water quality becomes progressively poorer. This depends upon the number of water quality variables for the objectives or guidelines that are not met (Factor 1), the percentage of time they are not met (Factor 2), and an equation which uses the normalized sum of departures from objectives (Factor 3).

For example, progressively smaller index values result when guidelines or objectives are exceeded for more water quality variables (*i.e.*, excursions for one variable will have less impact on water uses than simultaneous excursions for many water quality variables), when excursions occur during longer periods of time (*i.e.*, an exceedence for a brief period will have less impact on a water use than an exceedence for an extended period), and when the overall magnitude of excursions increase (*i.e.*, an exceedence slightly above a water quality guideline or objective will have less impact on a water use than an exceedence that is several times higher). Thus, the index logically incorporates information on water quality based on comparisons to guidelines or objectives to protect important water uses. The CWQI ranges from 0 to 100 and was used to rank water quality in categories ranging from poor to excellent. An excellent CWQI rating (85-100) indicates that all water uses are protected, with a virtual absence of impairment or only a minimal degree of impairment. A good water CWQI rating (70-84) indicates that all water quality uses are protected with only a minor degree of impairment. A fair CWQI rating (55-69) indicates that most water uses are protected but a few may be impaired. A marginal CWQI rating (40-54) indicates that several water uses may be impaired while a poor CWQI rating (0-39) indicates that most water uses are impaired.

RESULTS AND DISCUSSION

The emphasis in the Setting Lake study was on changes in phosphorus, nitrate-nitrite nitrogen, ammonia, total Kjeldahl nitrogen, chlorophyll *a*, turbidity, and bacteria over the summer of 2000. Temperature, pH, and conductivity were also measured in water samples from Setting Lake over the summer of 2000. Average values for these variables are shown for each sampling date and at each of four sites for Setting from June 22 to September 15. Appendix 1 includes all individual sample results of analyses for each sample for the variables noted in Table 1. Analytical results for over 100 variables measured in water samples collected on June 22, 2000 are shown in Table 2 for Setting Lake.

Nutrients

Nutrients required for the growth of algae and other plants include phosphorus and nitrogen compounds. Analyses were conducted for phosphorus, ammonia-ammonium nitrogen (also known as total ammonia), nitrate-nitrite nitrogen, and total Kjeldahl nitrogen, Figures 2 and 3.

Phosphorus often limits algae growth since it is likely to be the least abundant nutrient. During

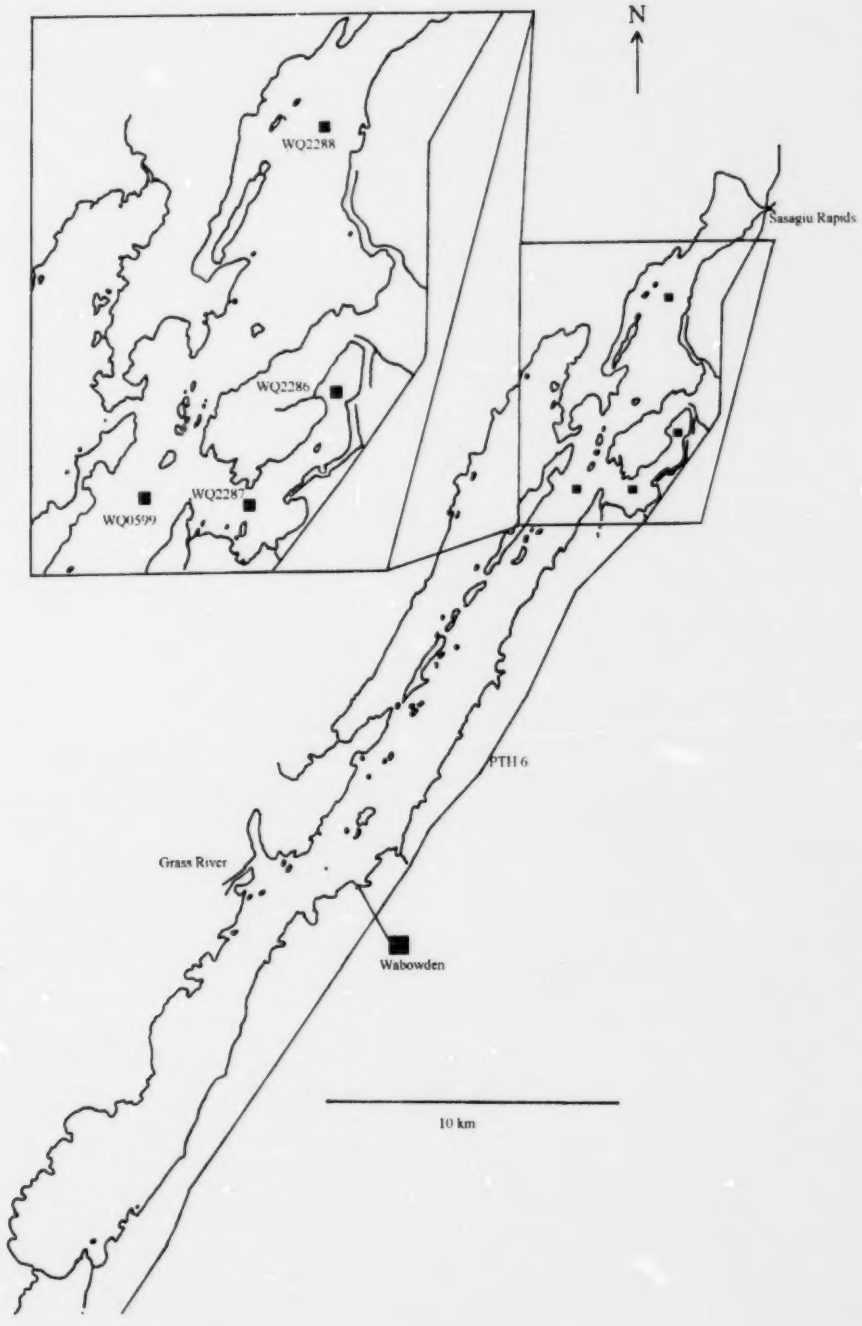

Figure 1. Setting Lake water quality sampling sites.

Table 1. Average chemical, physical, and biological variables, Setting Lake, 2000.

		Date							Site				
Variable	Units	22-Jun-00	03-Jul-00	16-Jul-00	30-Jul-00	14-Aug-00	28-Aug-00	09-Sep-00	WQ2286	WQ2287	WQ0599	WQ2288	All
Temperature	Degrees C	13.5	NA	13.0	NA	17.0	16.0	NA	14.8[a]	14.6[a]	14.2[a]	14.8[a]	14.6[a]
Fecal Coliform Bacteria	Bactena/100 mL	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
E-Coli Bactena	Bactena/100 mL	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
pH	pH units	7.78	7.87	7.99	8.03	7.92	7.89	7.92	7.91	7.90	7.89	7.95	7.91
Specific Conductivity	uS/cm	162	160	158	159	161	160	163	160	160	159	161	160
Turbidity	NTU	5.0	6.4	6.9	3.4	4.9	6.0	7.2	7.3	5.8	4.7	5.0	5.7
Secchi Disc	m	1.70	1.25	1.20	NA	1.55	1.30	NA	1.24[b]	1.34[b]	1.55[b]	1.47[b]	1.40[b]
Total Ammonia	mg/L	0.007	0.005	0.018	0.008	0.010	0.010	0.008	0.009	0.008	0.011	0.009	0.009
Nitrate-Nitrite	mg/L	0.01	< 0.01	< 0.01	0.02	< 0.01	< 0.01	0.01	0.01	0.01	0.02	0.01	0.01
Total Kjeldahal Nitrogen	mg/L	0.61	0.40	0.58	0.60	0.65	0.50	0.68	0.61	0.56	0.57	0.56	0.57
Total Phosphorus	mg/L	0.019	0.019	0.023	0.015	0.017	0.019	0.022	0.020	0.020	0.018	0.018	0.019
Particulate Phosphorus	mg/L	0.010	0.011	0.016	0.011	0.011	0.010	0.014	0.013	0.010	0.011	0.011	0.011
Dissolved Phosphorus	mg/L	0.009	0.008	0.007	0.004	0.006	0.010	0.008	0.007	0.009	0.007	0.007	0.007
Chlorophyll a	ug/L	3.6	2.8	3.8	8.0	5.0	8.3	6.0	4.8	6.9	5.4	4.3	5.3

a Temperature only available for five sets of samples.

b Secchi disc depth only available for five sets of samples.

Table 2. All physical, chemical and biological variables, Setting Lake, June 22 and July 3, 2000.

Site	Units	WQ2286	WQ2286	WQ2286	WQ2287	WQ2287	WQ2287	WQ0599	WQ0599	WQ0599	WQ2288	WQ2288	WQ2288	Average
Year		2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Date		22-Jun	22-Jun	3-Jul	22-Jun	22-Jun	3-Jul	22-Jun	22-Jun	3-Jul	22-Jun	22-Jun	3-Jul	
Depth Sample	m 22-Jun	0.1	3.5	NA	0.1	7.1	NA	0.1	8.1	NA	0.1	5.7	NA	3.1
Depth Total	m 22-Jun	NA	4.5	NA	NA	8.1	NA	NA	9.1	NA	NA	6.7	NA	7.1
Depth Composite[1]	m 3-Jul	NA	NA	2.0	NA	NA	2.4	NA	NA	3.0	NA	NA	2.6	2.5
Temperature	Degrees C	14.0	14.0	NA	14.0	13.0	NA	13.0	12.0	NA	14.0	14.0	NA	13.5
Bacteria														
Fecal Coliform	Bacteria/100 mL	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
E-Coli	Bacteria/100 mL	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
pH	pH Units	7.82	7.71	7.76	7.84	7.6	7.86	7.84	7.74	7.87	7.84	7.84	7.98	7.81
Specific														
Conductivity	uS/cm	163	163	159	162	162	160	160	160	158	164	163	161	161
Solids														
Total Dissolved	mg/L	80	110	120	110	110	110	110	100	110	110	120	120	109
Total Suspended	mg/L	< 5	5	8	5	6	6	< 5	< 5	< 5	6	7	< 5	< 6
Turbidity	NTU	5.1	6.5	9.5	4.6	6.3	7.1	4.1	5.6	5	3.8	3.9	4.1	5.5
Secchi Disc	m	1.60	NA	1.00	1.70	NA	1.20	1.75	NA	1.50	1.75	NA	1.30	1.48
True Colour	Colour Units	30	30	30	20	20	30	30	35	30	20	20	30	27
Alkalinity														
Total Alkalinity	mg/L	76	75	71	76	75	73	75	71	73	72	73	78	74
Bicarbonate	mg/L	93	92	87	93	91	89	92	87	89	88	89	95	90
Carbonate	mg/L	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20
Hydroxide	mg/L	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Dissolved Oxygen	mg/L	9.8	10.1	NA	9.3	NA	NA	10.7	9.9	NA	10.4	10.1	NA	10.0
Nitrogen														
Total Ammonia	mg/L	0.004	0.004	0.003	0.010	0.010	0.003	0.004	0.010	0.002	0.010	0.004	0.010	0.006
Nitrate-Nitrite	mg/L	0.01	0.01	< 0.01	0.02	0.01	< 0.01	0.01	0.02	< 0.01	0.01	0.01	< 0.01	< 0.02
Kjeldahal Nitrogen	mg/L	0.70	0.60	0.40	0.60	0.60	0.40	0.60	0.60	0.40	0.60	0.60	0.40	0.54
Phosphorus														
Total P	mg/L	0.018	0.022	0.022	0.019	**0.026**[2]	0.019	0.016	0.019	0.016	0.016	0.015	0.017	0.018
Particulate P	mg/L	0.009	0.012	0.015	0.010	0.015	0.011	0.007	0.009	0.008	0.008	0.006	0.010	0.010
Dissolved P	mg/L	0.009	0.010	0.007	0.009	0.011	0.008	0.009	0.010	0.008	0.008	0.009	0.007	0.009
Chlorophyll a	ug/L	7	4	2	4	3	4	3	2	3	4	2	2	3
Carbon														
Total C	mg/L	31	31	NA	32	34	NA	31	31	NA	33	33	NA	32
Total Inorganic C	mg/L	17	17	NA	17	17	NA	17	17	NA	17	17	NA	17
Total Organic C	mg/L	14	14	NA	15	17	NA	14	14	NA	16	16	NA	15
Chloride	mg/L	2.2	2.2	NA	2.4	2.3	NA	2.2	2.2	NA	2.2	2.4	NA	2.3
Sulphate	mg/L	3.0	2.8	NA	3.2	2.9	2.6	2.9	4.2	2.4	2.9	2.8	2.4	2.9
Total Hardness	mg/L	78.3	78.6	75.8	78.8	75.5	76.2	76.8	77	74.3	74.7	71.8	73.8	76.0
Total Calcium	mg/L	18.9	19.2	18.7	19.3	18.2	18.6	18.7	18.9	18	17.8	17.2	17.8	18.4
Total Magnesium	mg/L	7.55	7.45	7.08	7.44	7.3	7.23	7.32	7.24	7.13	7.35	7.02	7.14	7.27
Total Potassium	mg/L	1.20	1.28	1.32	1.24	1.19	1.34	1.23	1.28	1.25	1.06	0.94	1.20	1.21
Total Sodium	mg/L	2.89	3.02	3.17	2.97	2.88	3.26	2.90	2.96	3.05	2.75	2.57	2.97	2.95
Trace Elements														
Total Aluminum	mg/L	0.34	0.47	0.50	0.35	0.46	0.40	0.30	0.42	0.24	0.22	0.22	0.31	0.35
Dissolved Aluminum	mg/L	0.05	0.05	0.06	0.04	0.05	0.05	0.04	0.05	0.04	0.04	0.04	0.03	0.05
Total Arsenic	mg/L	0.0006	0.0009	0.0026	< 0.0005	0.0009	0.0025	0.0006	0.0009	0.0012	0.001	0.0006	0.0012	0.0011
Total Antimony	mg/L	< 0.001	< 0.001	0.001	< 0.001	< 0.001	0.001	< 0.001	< 0.001	0.001	< 0.001	< 0.001	0.001	< 0.001
Total Barium	mg/L	0.0124	0.0136	0.0123	0.012	0.012	0.011	0.011	0.0122	0.0116	0.0095	0.0111	0.0104	0.0116
Total Beryllium	mg/L	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Total Boron	mg/L	< 0.01	< 0.01	0.02	< 0.01	0.02	0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.02
Total Bismuth	mg/L	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Total Cadmium	mg/L	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Total Chromium	mg/L	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Total Cobalt	mg/L	< 0.0002	< 0.0002	0.0002	< 0.0002	< 0.0002	0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Total Copper	mg/L	0.002	0.001	NA	0.002	0.002	NA	0.002	0.002	NA	0.001	0.002	NA	0.0018
Total Cesium	mg/L	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Total Iron	mg/L	0.19	0.25	0.28	0.19	**0.32**[3]	0.23	0.14	0.23	0.16	0.10	0.10	0.16	0.18
Total Lead	mg/L	< 0.0005	< 0.0005	0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	0.0006	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Total Lithium	mg/L	0.003	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.002	0.0028
Total Manganese	mg/L	0.0088	0.0114	0.0102	0.0092	0.0152	0.0085	0.0096	0.0211	0.0071	0.0066	0.009	0.0078	0.0104
Total Molybdenum	mg/L	< 0.0001	< 0.0001	0.0002	< 0.0001	0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0001	< 0.0001
Total Nickel	mg/L	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Total Rubidium	mg/L	0.0015	0.0017	0.0019	0.0015	0.0019	0.0017	0.0015	0.0017	0.0013	0.0013	0.0014	0.0015	0.0016
Total Selenium	mg/L	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Total Silver	mg/L	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004
Total Strontium	mg/L	0.0351	0.0359	0.0357	0.0358	0.0357	0.0353	0.0339	0.0351	0.0339	0.0347	0.0354	0.0354	0.0352
Total Thallium	mg/L	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Total Tin	mg/L	< 0.0005	0.0013	0.0028	0.0008	0.0015	0.001	0.0008	0.0014	0.0022	0.0014	0.0013	0.0011	0.0013
Total Tellurium	mg/L	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Total Titanium	mg/L	0.0115	0.0144	0.0137	0.0085	0.0152	0.0101	0.0078	0.0097	0.0051	0.0065	0.0071	0.0072	0.0097
Total Uranium	mg/L	0.0001	0.0001	0.0001	0.0001	< 0.0001	0.0001	0.0001	0.0001	0.0001	< 0.0001	< 0.0001	0.0001	< 0.0001
Total Vanadium	mg/L	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	< 0.001	0.001	< 0.001	< 0.001	< 0.0001
Total Tungsten	mg/L	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002

Table 2. All physical, chemical and biological variables, Setting Lake, June 22 and July 3, 2000 (continued).

Site	Units	WQ2286	WQ2286	WQ2286	WQ2287	WQ2287	WQ2287	WQ0599	WQ0599	WQ0599	WQ2288	WQ2288	WQ2288	Average
Year		2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Date		22-Jun	22-Jun	3-Jul	22-Jun	22-Jun	3-Jul	22-Jun	22-Jun	3-Jul	22-Jun	22-Jun	3-Jul	
Total Zinc	mg/L	< 0.02	< 0.02	0.04	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Total Zirconium	mg/L	0.0003	0.0004	0.0007	0.0004	0.0005	0.0004	0.0003	0.0005	0.0003	0.0002	0.0004	0.0003	0.0004
Pesticides														
2,4-D	ug/L	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05
2,4-DB	ug/L	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05
2,4-DP	ug/L	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05
Eptam	ug/L	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2
Alachlor	ug/L	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2
Atrazine	ug/L	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1
Lindane	ug/L	< 0.02	< 0.02	NA	< 0.02	< 0.02	NA	< 0.02	< 0.02	NA	< 0.02	< 0.02	NA	< 0.02
Bromacil	ug/L	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2
Bromoxynil	ug/L	< 0.02	< 0.02	NA	< 0.02	< 0.02	NA	< 0.02	< 0.02	NA	< 0.02	< 0.02	NA	< 0.02
Carbofuran	ug/L	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2
Cis-Chlordane	ug/L	< 0.01	< 0.01	NA	< 0.01	< 0.01	NA	< 0.01	< 0.01	NA	< 0.01	< 0.01	NA	< 0.01
Trans-Chlordane	ug/L	< 0.01	< 0.01	NA	< 0.01	< 0.01	NA	< 0.01	< 0.01	NA	< 0.01	< 0.01	NA	< 0.01
Chlorothalinal	ug/L	< 0.5	< 0.5	NA	< 0.5	< 0.5	NA	< 0.5	< 0.5	NA	< 0.5	< 0.5	NA	< 0.5
Clorpyrifos-Ethyl	ug/L	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1
Deltamethrin	ug/L	< 0.04	< 0.04	NA	< 0.04	< 0.04	NA	< 0.04	< 0.04	NA	< 0.04	< 0.04	NA	< 0.04
Diazinon	ug/L	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1
Dicamba	ug/L	< 0.02	< 0.02	NA	< 0.02	< 0.02	NA	< 0.02	< 0.02	NA	< 0.02	< 0.02	NA	< 0.02
Diclofop	ug/L	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1
Dimethoate	ug/L	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2
Dinoseb	ug/L	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05
Ethfluralin	ug/L	< 0.02	< 0.02	NA	< 0.02	< 0.02	NA	< 0.02	< 0.02	NA	< 0.02	< 0.02	NA	< 0.02
Fenoxaprop	ug/L	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1
Malathion	ug/L	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2
MCPA	ug/L	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05
Mecoprop	ug/L	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05
Metohxychlor	ug/L	< 0.04	< 0.04	NA	< 0.04	< 0.04	NA	< 0.04	< 0.04	NA	< 0.04	< 0.04	NA	< 0.04
Metribuzin	ug/L	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2
Pentachlorophenol	ug/L	< 0.02	< 0.02	NA	< 0.02	< 0.02	NA	< 0.02	< 0.02	NA	< 0.02	< 0.02	NA	< 0.02
Picloram	ug/L	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2
Propanil	ug/L	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2
Propoxur	ug/L	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2
Quizlofop	ug/L	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1
Simazine	ug/L	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1	< 0.1	NA	< 0.1
Terbufos	ug/L	< 0.5	< 0.5	NA	< 0.5	< 0.5	NA	< 0.5	< 0.5	NA	< 0.5	< 0.5	NA	< 0.5
Triallate	ug/L	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2	< 0.2	NA	< 0.2
Triclopyr	ug/L	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05	< 0.05	NA	< 0.05
Trifluralin	ug/L	< 0.03	< 0.03	NA	< 0.03	< 0.03	NA	< 0.03	< 0.03	NA	< 0.03	< 0.03	NA	< 0.03

1. Composite sample.

a. Excursions from objectives. Of 25 variables used in the CWQI assessment, single total phosphorus and total iron values minimally exceeded objectives and are indicated in bold type.

2000, the average total phosphorus in Setting Lake was 0.019 mg/L (Table 1). Total phosphorus concentrations that exceed the water quality objective of 0.025 mg/L have the potential to cause algae blooms in lakes (Williamson 1988, 2001). Except for a total phosphorus concentration of 0.026 mg/L in one sample collected near the bottom at site WQ02287 on June 22, 2000, all other total phosphorus values in Setting Lake water samples were below the objective of 0.025 mg/L (Appendix 1). In this case the excursion was only minor. Total phosphorus concentrations tended to vary over the summer and except for two peaks in mid-July and in mid-September the dissolved phosphorus tended to follow the same trend (Figure 2). There were no significant differences between sites for dissolved phosphorus. However, both the total and the particulate phosphorus were significantly higher ($\alpha = 0.05$) at site WQ2286 relative to sites WQ0599 and WQ2288. There was not a significant difference in total or particulate phosphorus between sites WQ2286 and WQ2287 that are located in the bay area (Figure 1). The two sites in bay area tended to have the highest overall average total phosphorus partly because of the shallowness of these sites and partly due to more intense boating activity particularly near site WQ2286. In shallower areas wind and wave action and boating activity would have a greater tendency to re-suspend particulate phosphorus from bottom sediments. Also, there may some other additional phosphorus contributed due to antropogenic activities such as the use of fertilizer for lawns or poorly operating sewage systems.

Nitrogen compounds were present at low concentrations for ammonia, and nitrate-nitrite, but moderate concentrations of total Kjeldahl nitrogen in Setting Lake (Table 1, Figure 3, and Appendix 1). Total Kjeldahl nitrogen fluctuated considerably over the summer (Figure 2). Average total Kjeldahl nitrogen concentrations were 0.57 mg/L (Table 1). Although total Kjeldahl nitrogen concentrations were generally higher at site WQ2286 than at the other sites there were no significant differences ($\alpha = 0.05$) between sites (Figure 3). There were no significant differences between sites for either nitrate-nitrite or total ammonia. Nitrate-nitrite nitrogen concentrations were at or near detection limits of 0.01 mg/L and were well below the water quality objective to protect drinking water of 10 mg/L. Total ammonia concentrations were also low with an overall average of 0.009 mg/L in Setting Lake. Total ammonia concentrations were well below water quality objectives in all cases. Objectives for total ammonia relate to the protection of aquatic life and vary depending on temperature and pH.

Turbidity

Turbidity rises with increases in suspended particulate material (total suspended solids). The average turbidity in Setting Lake was relatively low at 5.7 NTU (Table 1). Turbidity was significantly higher at site WQ2286 relative to sites WQ0599 and WQ2288 ($\alpha = 0.05$) but not significantly higher relative to site WQ2287 (Figure 4). The turbidity at site WQ2287 was significantly higher than at site WQ0599 but not significantly higher than at site WQ2288. Average turbidity at sites WQ2286 and WQ2287 in the shallower bay area were above the aesthetic objective of 5 NTU. This was probably due to wind and wave action and more intensive boating activity as previously noted under the discussion of phosphorus with respect to re-suspension of particulate materials.

The Secchi disk transparency provides a visual estimate of water clarity. Data was only available for five sets of Secchi disc measurements. However, a best-fit regression for turbidity verses Secchi disc provided estimates for the remaining two sampling occasions and indicated that the average transparencies were likely slightly better than if estimates were not included. The average Secchi disc transparencies for five samples, with average Secchi disc transparencies including the additional estimates noted in brackets were as follows: 1.24 (1.26), 1.34 (1.42), 1.55 (1.58), and 1.47 (1.48) m, at sites WQ2286, WQ2287, WQ0599, WQ2288, respectively (Figure 1). The overall average transparency was 1.40 (1.44) m indicating moderate to good water clarity. Average Secchi disc transparencies in 1981, 1982, and 1983 were 1.96, 1.75, and 1.93 m respectively. The average monthly Secchi disc values

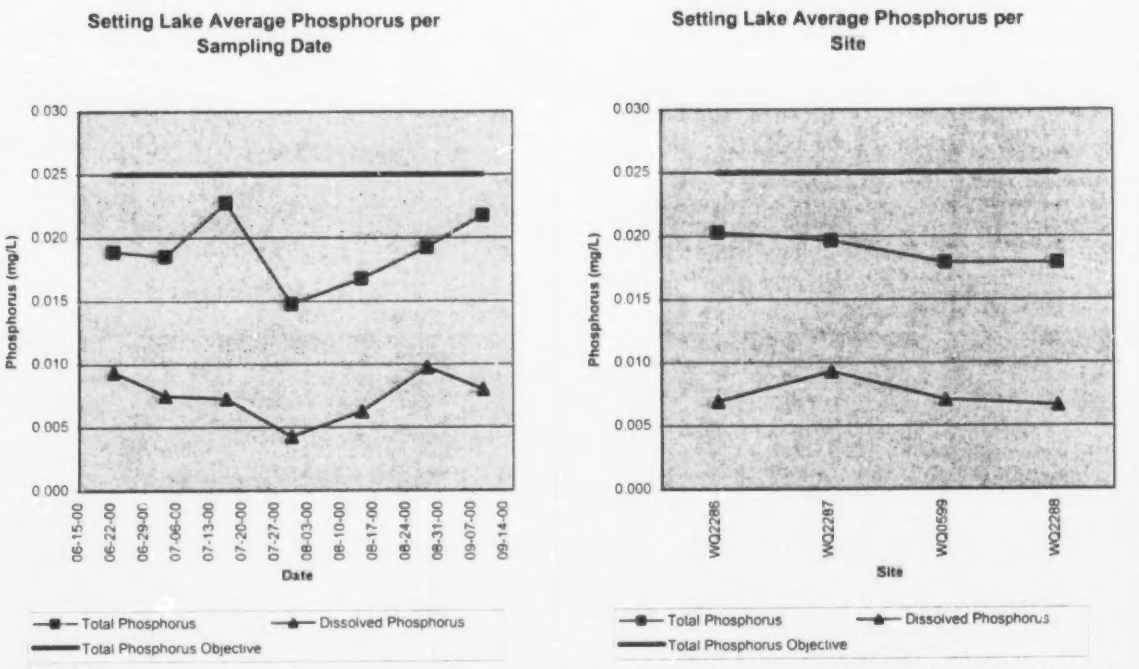

Figure 2. Average total and dissolved phosphorus, Setting Lake in 2000.

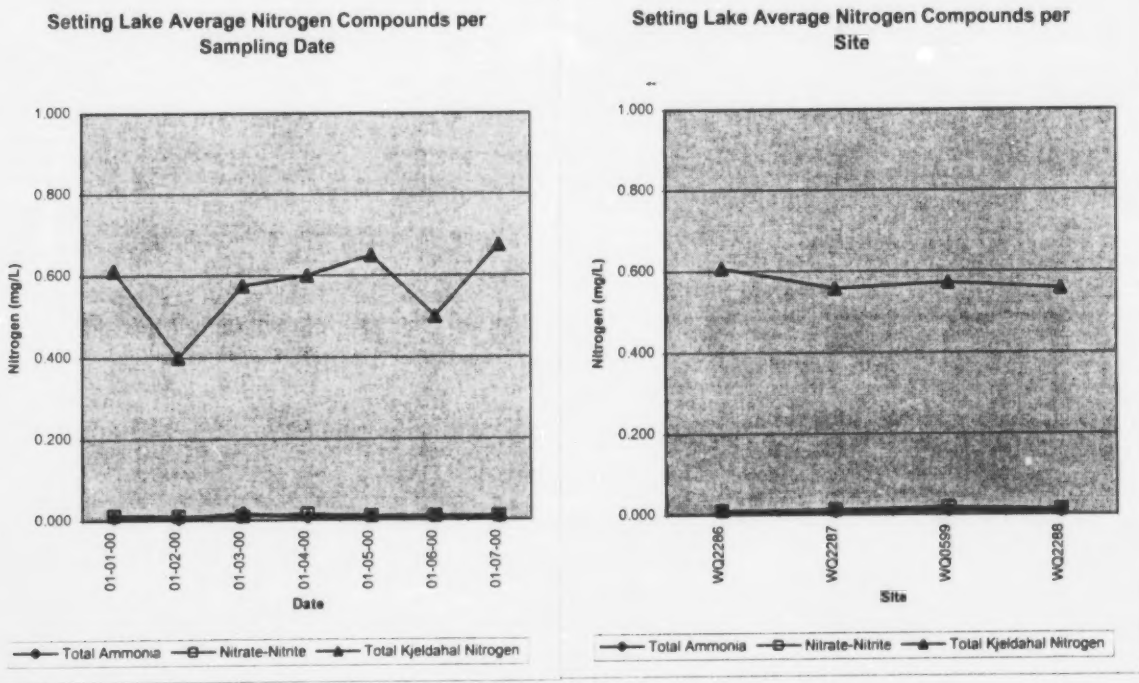

Figure 3. Average ammonia, nitrate-nitrite and total Kjeldahal nitrogen, Setting Lake in 2000.

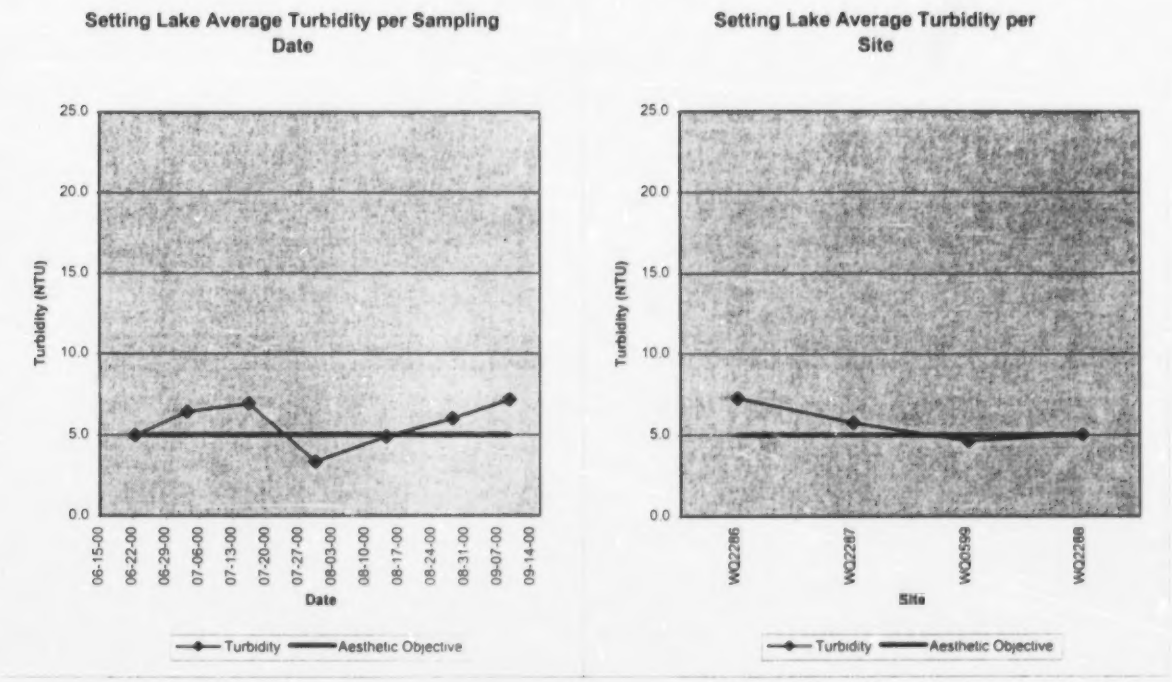

Figure 4. Average turbidity, Setting Lake in 2000.

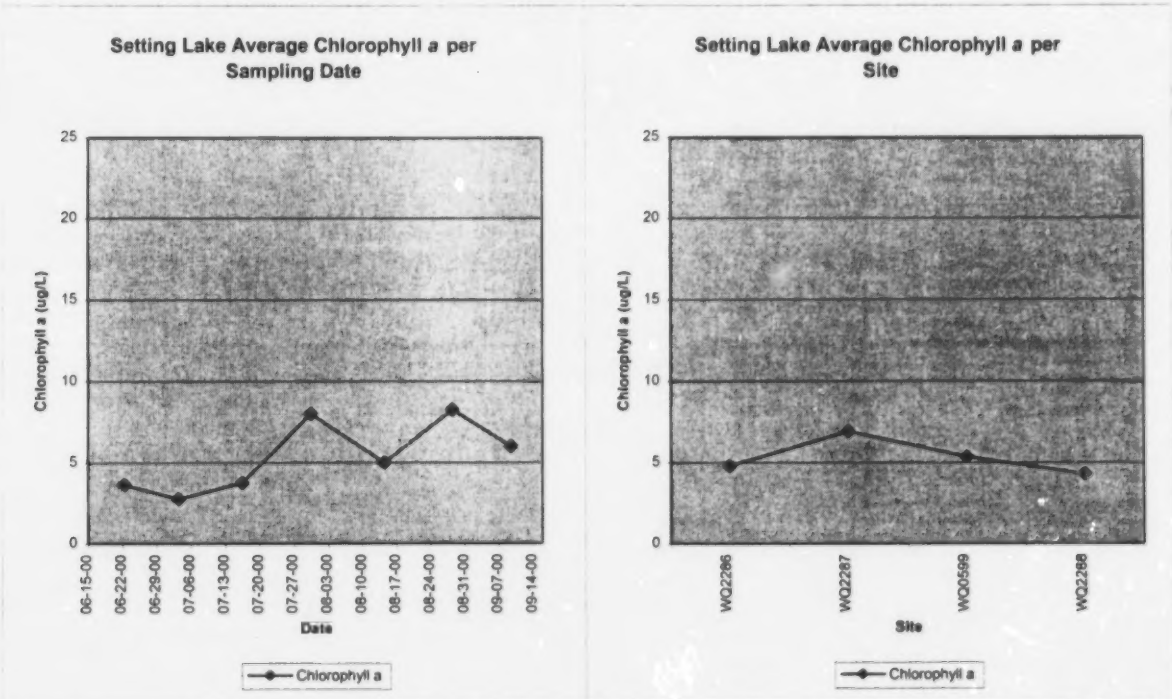

Figure 5. Average chlorophyll *a*, Setting Lake in 2000.

showed significantly better water clarity ($\alpha = 0.05$) in 1981 and 1983 than in 2000. However, water clarity was also significantly better ($\alpha = 0.05$) in 1981 than 1982 indicating annual variability.

Chlorophyll a

Except for June 22, 2000 where samples were collected at the surface 1 m off the bottom chlorophyll *a* was analyzed from samples collected through the water column within the euphotic zone. A depth of twice the Secchi disk depth is the approximate depth of the euphotic zone, or zone of light penetration where algae photosynthesis can occur. Chlorophyll *a* was extracted from the algae in the water samples. In 2000, chlorophyll *a* concentrations were low to moderate in Setting Lake with an overall average of 5.3 µg/L per site. There were no significant differences ($\alpha = 0.05$) between sites in 2000 (Table 1 and Appendix 1). Average annual chlorophyll *a* concentrations were 1.9, 1.2, and 1.3 µg/L in 1981, 1982, and 1983, respectively. Although the average annual chlorophyll *a* concentrations in the 1980s appear to be considerably lower than in 2000 many of the samples in the 1980s sets of data were collected in June when chlorophyll *a* concentrations tend to be lower. When average monthly chlorophyll *a* concentrations from all four years were compared there were no significant differences between the 2000 data and any of the other three years ($\alpha = 0.05$).

In 2000, chlorophyll *a* in Setting Lake generally corresponded with increases in total phosphorus and turbidity until the temperature would have begun to decline in September (Table 1 and Figures 2, 4, and 5). The only occasion where this was not the case was on July 30, 2000. A chlorophyll *a* value from site WQ2287 was 19 µg/L on this date and tended to distort the overall average for the day and for site WQ2287 (Figure 5). On the same day both average total phosphorus and average turbidity were the lowest observed throughout the summer (Figures 1 and 4). The occasional higher chlorophyll *a* at one site relative to other sites can occur when wind and wave action can push accumulations of algae nearer to one shore than another.

Fecal Coliform Bacteria

Fecal coliform bacteria including *E. coli* counts were at or less than the detection limit of 10 organisms/100 mL of water in Setting Lake over the summer of 2000 (Appendix 1). All the fecal coliform bacteria counts were well below the recommended objective for recreational water quality of 200 organisms/100 mL (Williamson 1988, 2001) and there were no significant differences ($\alpha = 0.05$) between sites. However, as with all surface waters, if water from the lake is used as a domestic water source it should always be boiled or disinfected before it is used for drinking.

pH

During the summer of 2000 the pH values in Setting Lake ranged from 7.71 to 8.03 (Appendix 1). The pH values were within the objective range of 6.5 and 9.0 recommended for the protection of aquatic life (Williamson 1988, 2001). There were no significant differences ($\alpha = 0.05$) for pH values between sites (Table 1 and Figure 6).

Specific Conductivity

Specific conductivity is a measure of the dissolved salts in water and is closely related to total dissolved solids. During the summer of 2000 the conductivity in Setting Lake ranged from 157 to 164 µS/cm (Appendix1). These were well below the recommended objective of 1000 µS/cm (Williamson 1988, 2001). There were significant increases ($\alpha = 0.05$) in conductivity between site WQ0599 and sites WQ2886, and WQ2888 (Table 1 and Figure 7). There was also a significant increase in conductivity

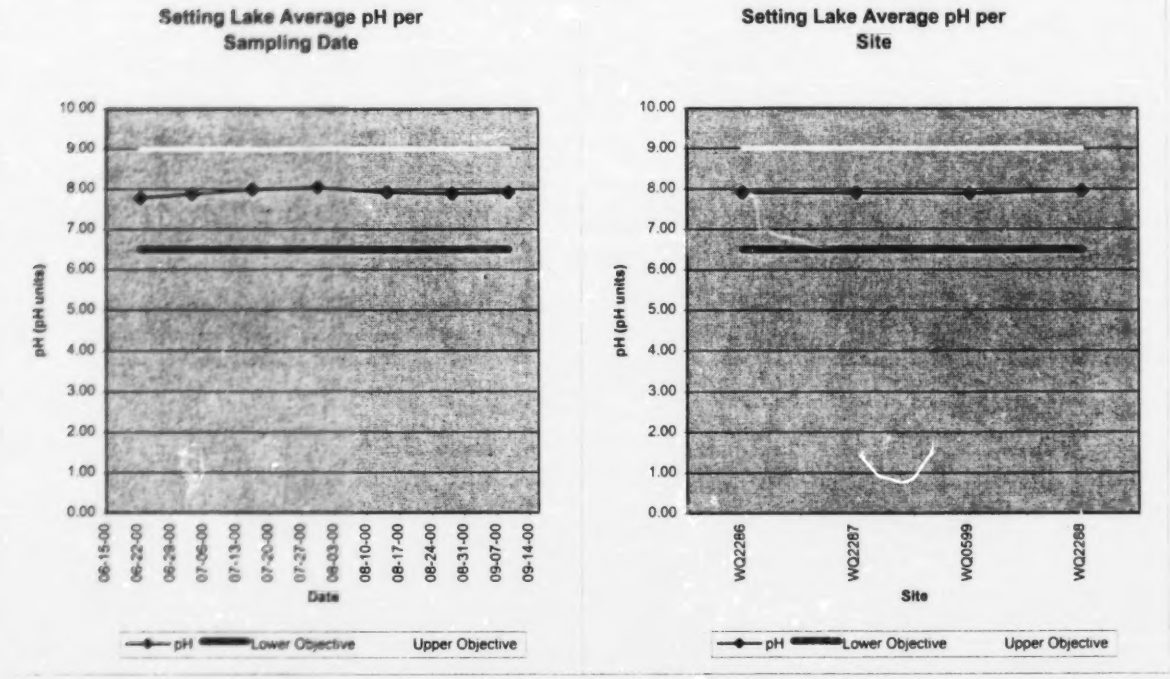

Figure 6. Average pH, Setting Lake in 2000.

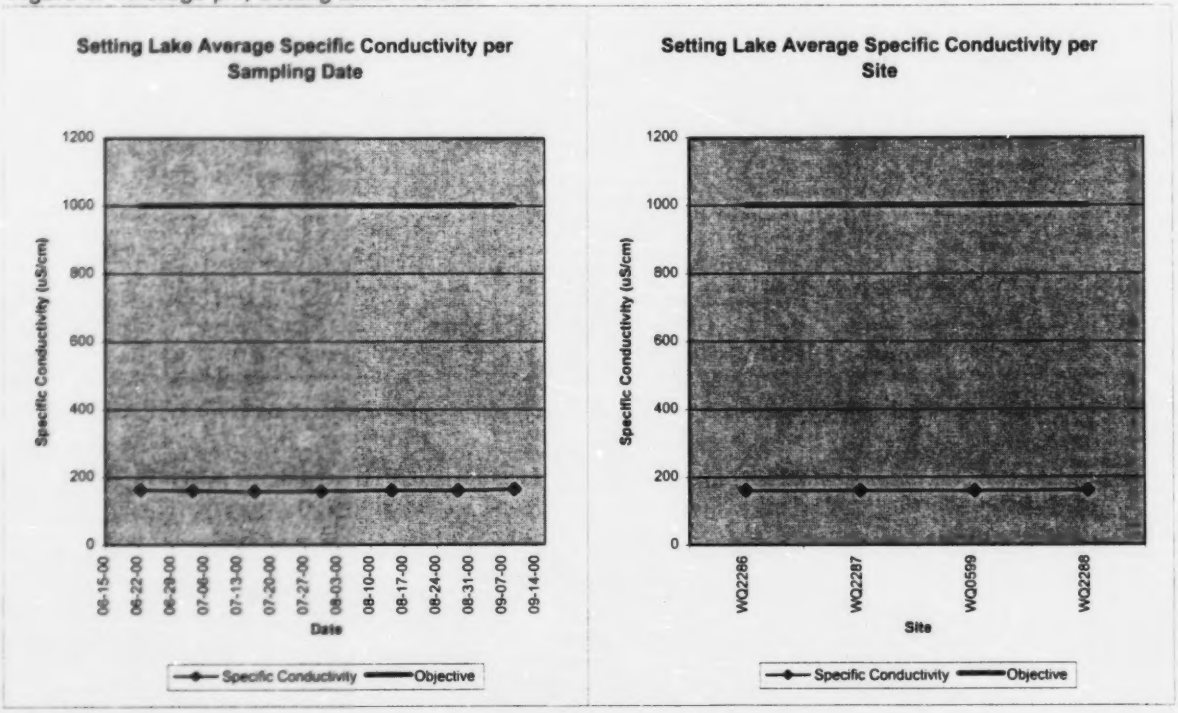

Figure 7. Average specific conductivity, Setting Lake in 2000.

between sites WQ2887 and WQ2888. However, the real differences in conductivity were very small and were within the boundaries of analytical variation.

Water Quality on June 22 and July 3, 2000

Results for over 100 variables measured in water samples collected on June 22, 2000 and July 3, 2000 are shown in Table 2 and Appendix 1 for Setting Lake. Of these, 25 variables were used to calculate the water quality indices for Setting Lake. Variables used in this index included total phosphorus, un-ionized ammonia, fecal coliform bacteria, pH and specific conductivity that have already been discussed. The following is a discussion of other variables that were also used.

Total suspended solids in Setting Lake on June 22, 2000 (Table 2) ranged from < 5 to 8 mg/L, well below the objective of 25 mg/L (Williamson 1988, 2001). It is unlikely that suspended solids would have exceeded the objective since the turbidity never exceeded 10 NTU (Appendix 1).

Dissolved oxygen is essential to the survival of fish stocks. Dissolved oxygen concentrations ranged from 9.8 to 10.7 mg/L (Table 2). These dissolved oxygen concentrations were well over the 5 mg/L objective recommended for the maintenance of cool water aquatic life (Williamson 1988, 2001).

Trace element analyses from water samples collected from Setting Lake on June 22, and July 3, 2000 included total concentrations of cadmium, copper, nickel, lead, zinc, arsenic, and dissolved aluminum. In Setting Lake, the total cadmium, nickel, zinc, and lead concentrations were all below detection limits while total copper and arsenic concentrations were near detection limits (Tables 2). All these elements were below their respective objectives (Williamson 1988, 2001). The objective for aluminum is dependent on pH and in all cases the objective was 0.1 mg/L. There were no excursions of the dissolved aluminum objective in Setting Lake.

Iron and manganese are of an aesthetic concern in drinking water but can be removed with treatment. One total iron concentration of 0.32 mg/L was slightly above the recommended objective of 0.3 mg/L (Williamson 1988, 2001). The remainder of the iron concentrations were well below the recommended objective for iron (Table 2). All total manganese concentrations were well below the recommended objective for manganese of 0.05 mg/L (Williamson 1988, 2001).

Pesticide analyses were conducted on water samples collected from Setting Lake on June 22, 2000. None of the 37 pesticides were detected (Tables 3 and 4).

The Canadian Water Quality Index (CWQI) for Setting Lake was based on 25 variables that have been previously discussed. Figure 8 shows the CWQI rating for Setting Lake as well as five other northern Manitoba lakes including Paint, Liz, and Clearwater lakes. These indices indicated "Excellent" water quality for all four lakes with CWQI falling in the range of 95 to 100 (Appendix 2). Of the two lakes studied in 2000, Setting Lake rated 95.4 similar to Snow Lake with a rating of 95.3. These are both "Excellent" scores. The only lake that rated a perfect score of 100 was Liz Lake in 1998, where there were no exeedences of any of the 25 objectives.

A water quality index rating of "Excellent" indicates that:

- all water uses are protected, with a virtual absence of impairment or only a minimal degree of impairment,
- no water uses are ever interrupted and,
- conditions rarely depart from desirable quality.

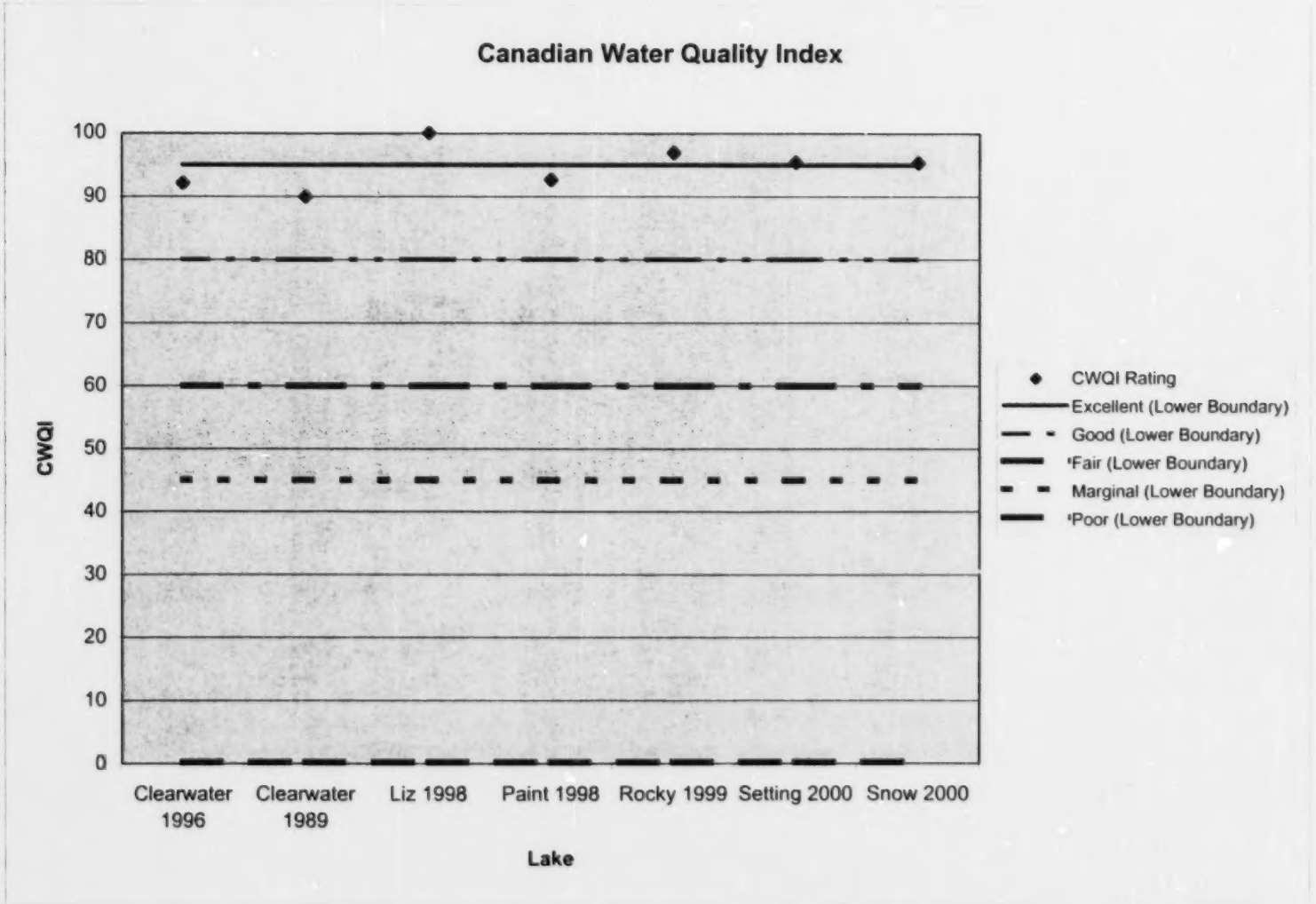

Figure 8. Annual Canadian Water Quality Indices for six northern Manitoba lakes.

CONCLUSIONS

The Setting Lake study involved water quality sampling at two sites located upstream and downstream of the main cottage development. There were two additional water quality sites inside and just outside of a cottage development. Differences in water quality between the bay area and the main body of the lake are due in part to differences in depth where the shallower bay area would be more influenced by wind and wave action and by more concentrated boating activity. Overall, the water quality in Setting Lake was excellent.

- maintained excellent bacteriological characteristics but, as with all surface waters, lake water should always be boiled or disinfected before use for drinking water;
- trace metal concentrations were very low and many were below detection limits. There was only one minor excursion of objectives for iron;
- pesticide concentrations were below detection limits;
- dissolved oxygen concentrations were excellent;
- although total nitrogen increased over the summer, un-ionized ammonia and nitrate-nitrite nitrogen remained low and well below water quality objectives;
- dissolved phosphorus concentrations were fairly low and remained relatively stable throughout the summer of 2000;
- total phosphorus concentrations were generally low and exceeded the water quality objective only once and this was a minor excursion. Total phosphorus was significantly higher in the shallower bay area relative to the main body of the lake. It appears that particulate phosphorus was added to the water column due largely to wind and wave action and possibly boating activity stirring up bottom sediments;
- turbidity was significantly higher in the bay area. The shallower bay area was significantly more turbid and subsequently produced higher total phosphorus values than were observed in the main body of the lake. It is possible that a reduction in boating activity might reduce the turbidity in the shallower bay area. Also, maintenance of vegetation along the shoreline will reduce any shoreline erosion which may occur;
- chlorophyll *a* extracted from algae was generally low and there was no significant difference between sites. Although total phosphorus was relatively high in September 2000, there was a decline in algae growth due to lower temperatures;
- the pH was not significantly different between sites;
- the specific conductivity increased significantly from the upstream to the downstream in the main body of the lake. The conductivity in the shallower developed portion of the bay area was significantly greater than at the upstream site in the main lake but not significantly different from the downstream site in the main body of the lake. Despite these differences, increases in conductivity were minor and conductivity was well below water quality objectives;
- although there were differences in water quality between the main body of the lake and the bay area, the overall water quality index (CWQI) rated the water quality in Setting Lake as "Excellent";
- Cottage owners should be aware of a number of things that they can do or avoid doing in order to continue to maintain excellent water quality in Setting Lake. Avoid using shampoo or detergent in the lake. Ensure that grey water from washing does not enter the lake. The general move in the cottage development to holding tanks for sewage and grey water is a big step toward keeping the lake water clean. Also, although turbidity was not particularly high at any of the sampling sites, cottagers should also keep in mind that excessive boating activity in shallower areas and bays can add to the turbidity due to motors stirring up bottom sediments.

ACKNOWLEDGMENTS

We do greatly appreciate the volunteers who conducted most of the water sampling on Setting Lake. These included: Alex Gaudet, and Ray Mintenko who did most of the sample collection and Ms. Berny Jacob, and Greg Pelchat who also volunteered. We are also grateful for the assistance of Steve Davis, Stefane Gravelle, April Gravelle of Manitoba Conservation.

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Appendix 1

Appendix 1. All chemical, physical, and biological variables (excluding extra variables from June 22 and July 3, 2000 samples), Setting Lake, 2000.

Site	Sample Type	Date	Temperature	Bacteria Fecal Coliform	Bacteria E-Coli	pH	Specific Conductivity	Turbidity	Secchi Disc	Nitrogen Total Ammonia	Nitrogen Nitrate-Nitrite	Nitrogen Total Kjeldahal	Phosphorus Total	Phosphorus Particulate	Phosphorus Dissolved	Chlorophyll a
Units			Degrees C	Bacteria/100mL	Bacteria/100mL	pH units	uS/cm	NTU	m	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ug/L
WQ2286	Surface	22-Jun-00	14.0	< 10	< 10	7.82	163	5.1	1.60	0.004	0.01	0.7	0.018	0.009	0.009	7
WQ2286	Bottom	22-Jun-00	14.0	< 10	< 10	7.71	163	6.5	NA	0.004	0.01	0.6	0.022	0.012	0.010	4
WQ2286	Composite	03-Jul-00	NA	< 10	< 10	7.76	159	9.5	1.00	0.003	< 0.01	0.4	0.022	0.015	0.007	2
WQ2286	Composite	16-Jul-00	13.0	< 10	< 10	8.09	158	9.0	1.10	0.020	< 0.01	0.5	0.024	0.016	0.008	4
WQ2286	Composite	30-Jul-00	NA	< 10	< 10	8.01	159	4.1	NA	0.010	0.01	0.8	0.016	0.012	0.004	4
WQ2286	Composite	14-Aug-00	17.0	< 10	< 10	7.95	161	5.9	1.30	0.004	< 0.01	0.6	0.018	0.012	0.006	5
WQ2286	Composite	28-Aug-00	16.0	10	10	7.91	160	6.6	1.20	0.010	0.01	0.5	0.018	0.012	0.006	7
WQ2286	Composite	09-Sep-00	NA	< 10	< 10	7.88	163	10.0	NA	0.010	< 0.01	0.8	0.024	0.016	0.008	6
WQ2286	Composite															
WQ2287	Surface	22-Jun-00	14.0	< 10	< 10	7.84	162	4.6	1.70	0.010	0.02	0.6	0.019	0.010	0.009	4
WQ2287	Bottom	22-Jun-00	13.0	< 10	< 10	7.60	162	6.3	NA	0.010	0.01	0.6	**0.026**	0.015	0.011	3
WQ2287	Composite	03-Jul-00	NA	< 10	< 10	7.86	160	7.1	1.20	0.003	< 0.01	0.4	0.019	0.011	0.008	4
WQ2287	Composite	16-Jul-00	13.0	< 10	< 10	7.96	157	7.5	1.10	0.010	< 0.01	0.6	0.023	0.016	0.007	4
WQ2287	Composite	30-Jul-00	NA	< 10	< 10	8.04	158	3.2	NA	0.007	0.01	0.5	0.014	0.010	0.004	19
WQ2287	Composite	14-Aug-00	17.0	10	< 10	7.97	161	5.1	1.50	0.010	< 0.01	0.7	0.016	0.009	0.007	5
WQ2287	Composite	28-Aug-00	16.0	< 10	< 10	7.83	160	5.9	1.20	0.010	< 0.01	0.5	0.024	0.003	0.021	7
WQ2287	Composite	09-Sep-00	NA	< 10	< 10	7.92	162	6.0	NA	0.006	< 0.01	0.6	0.019	0.011	0.008	6
WQ0599	Surface	22-Jun-00	13.0	< 10	< 10	7.84	160	4.1	1.75	0.004	0.01	0.6	0.016	0.007	0.009	3
WQ0599	Bottom	22-Jun-00	12.0	< 10	< 10	7.74	160	5.6	NA	0.010	0.02	0.6	0.019	0.009	0.010	2
WQ0599	Composite	03-Jul-00	NA	< 10	< 10	7.87	158	5.0	1.50	0.002	< 0.01	0.4	0.016	0.008	0.008	3
WQ0599	Composite	16-Jul-00	13.0	10	10	7.96	157	6.0	1.10	0.020	< 0.01	0.6	0.022	0.015	0.007	4
WQ0599	Composite	30-Jul-00	NA	< 10	< 10	8.03	158	2.7	NA	0.010	0.02	0.6	0.016	0.012	0.004	5
WQ0599	Composite	14-Aug-00	17.0	10	< 10	7.88	160	3.8	1.90	0.020	< 0.01	0.7	0.016	0.010	0.006	6
WQ0599	Composite	28-Aug-00	16.0	< 10	< 10	7.82	160	5.0	1.50	0.010	< 0.01	0.4	0.017	0.011	0.006	9
WQ0599	Composite	09-Sep-00	NA	< 10	< 10	7.87	163	5.2	NA	0.008	0.02	0.7	0.021	0.012	0.009	8
WQ2288	Surface	22-Jun-00	14.0	< 10	< 10	7.84	164	3.8	1.75	0.010	0.01	0.6	0.016	0.008	0.008	4
WQ2288	Bottom	22-Jun-00	14.0	< 10	< 10	7.84	163	3.9	NA	0.004	0.01	0.6	0.015	0.006	0.009	2
WQ2288	Composite	03-Jul-00	NA	< 10	< 10	7.98	161	4.1	1.30	0.010	< 0.01	0.4	0.017	0.010	0.007	2
WQ2288	Composite	16-Jul-00	13.0	< 10	< 10	7.93	158	5.2	1.50	0.020	0.01	0.6	0.022	0.015	0.007	3
WQ2288	Composite	30-Jul-00	NA	< 10	< 10	8.05	159	3.4	NA	0.003	0.02	0.5	0.013	0.008	0.005	4
WQ2288	Composite	14-Aug-00	17.0	< 10	< 10	7.89	161	4.8	1.50	0.004	< 0.01	0.6	0.017	0.011	0.006	4
WQ2288	Composite	28-Aug-00	16.0	< 10	< 10	7.98	160	6.5	1.30	0.010	< 0.01	0.6	0.018	0.012	0.006	10
WQ2288	Composite	09-Sep-00	NA	< 10	< 10	8.00	163	7.4	NA	0.006	< 0.01	0.6	0.023	0.016	0.007	4
Objective			NA	200	200	6.5-9.0	1000	NA	NA	Calculated	10	NA	0.25	NA	NA	
Objective Excursions[1]				None	None	None	None			None	None		1			

1. Objective excurions marked in bold.

Appendix 2

Appendix 2. Canadian water quality index (CWQI), water quality variables and objectives or guidelines (Williamson 2000, Williamson 1988) used to calculate CWQI values (CCME 2000).

Variables	Units	Objective* Value	Objective* Use
Fecal Coliform MF	Bacteria/100mL	200	Recreation
Ph	Ph Units	6.5-9.0	Aquatic Life
Specific Conductivity	uS/cm	1000	Greenhouse Irrigation
Total Suspended Solids	mg/L	25 (mid range)	Aquatic Life
Dissolved Oxygen	mg/L	5 (mid range)	Aquatic Life
Total or Extractable Cadmium*	mg/L	Calculation based on Hardness (7Q10)	Aquatic Life
Total or Extractable Copper*	mg/L	Calculation based on Hardness (7Q10)	Aquatic Life
Total Arsenic	mg/L	0.025	Drinking Water, Health
Total or Extractable Lead*	mg/L	Calculation based on Hardness (7Q10)	Aquatic Life
Dissolved Aluminum	mg/L	0.1 for pH >6.5	Aquatic Life
Total or Extractable Nickel*	mg/L	Calculation based on Hardness (7Q10)	Aquatic Life
Total or Extractable Zinc*	mg/L	Calculation based on Hardness (7Q10)	Aquatic Life
Total or Extractable Manganese	mg/L	0.05	Drinking Water, Aesthetic
Total or Extractable Iron	mg/L	0.3	Drinking Water, Aesthetic
Total Ammonia as N	mg/L	Calculation based pH	Aquatic Life
Soluble or Dissolved Nitrate-Nitrite	mg/L	10	Drinking Water, Health
Total Phosphorus	mg/L	~~0.050~~ 0.025	Nuisance Plant Growth
Dicamba	ug/L	0.006 where detectable	Irrigation
Bromoxynil	ug/L	0.33	Irrigation
Simazine	ug/L	0.5	Irrigation
2,4 D	ug/L	4	Aquatic Life
Lindane	ug/L	0.08	Aquatic Life
Atrazine	ug/L	1.8	Aquatic Life
MCPA	ug/L	2.6 where detectable	Aquatic Life
Trifluralin	ug/L	0.2	Aquatic Life

* Calculation based on dissolved metals and may slightly over estimate excursions.

CWQI (CCME 2000) Category ranges: 95-100 Excellent; 80-94 Good; 60-79 Fair; 45-59 Marginal; 0-44 Poor

$CWQI = 100-(((F_1^2+F_2^2+F_3^2)^{1/2})/1.732)$

Scope F_1 = ((Number of variables with an objective not met)/(Total number of variables))x100

Frequency F_2 = ((Number of samples with an objective not met)/(Total number of samples))x100

Amplitude $F_3 = ((nse/(0.01nse + 0.01))$

Where *nse* is the normalized sum of test excursions:

$nse = (\text{Sum of excursions}_i)/(\text{Total number of tests})$

Where test values must not exceed the objective:

$\text{excursion}_i = (\text{Concentration}_i)/(\text{Objective}_j)$

Where test values must not fall below the objective:

$\text{excursion}_i = (\text{Objective}_j)/(\text{Concentration}_i)$

Where the objective is zero:

$\text{excursion}_i = \text{Concentration}_i$

Appendix 3

Synopsis of water chemistry variables that were detected or used in the water quality index.

Appendix 3. Synopsis of water chemistry variables that were detected or used in the water quality indices.

Summary and Interpretation of Aquatic Variables

Introduction

The following provides a brief synopsis of most of the water quality variables analyzed. The only exceptions to this are trace elements and pesticides that were not detectable and/or were not used for calculation of the Canadian Water Quality Index. The variables are listed alphabetically by name for quick reference. Each variable name is followed immediately by the units of measure in that it is most commonly reported. Also after each variable name is its chemical symbol or formula (in the case of compounds), and in most cases, the most commonly encountered ionized form of the variable in water. A short discussion of the uses, biological importance, potential sources, and general water chemistry of each variable is then summarized.

Alkalinity (mg/L)

Alkalinity is an indication of the buffering capacity of the water, that is the ability of the water to neutralize acid inputs. Alkalinity is usually reported as total alkalinity ($CaCO_3$), bicarbonate alkalinity (HCO_3), carbonate alkalinity (CO_3), and hydroxide alkalinity (OH). Although high alkalinity itself is not considered to be harmful, it is usually associated with high pH and high water hardness, and excessive dissolved solids.

Ammonia (mg/L) (NH_3 and NH_4^+)

Ammonia is an inorganic form of nitrogen that can be used directly for use by plants. Nitrogen itself is one of the three main macro-nutrients required by plants, and inadequate levels of a usable form of nitrogen in soil or water can severely limit plant growth and development. Natural sources of ammonia in surface waters include the decomposition of plant material and animal wastes, gas exchange with the atmosphere (pure ammonia being a gas and present in air), weathering of clays, and nitrogen fixation by micro-organisms. Ammonia is a major component in soil fertilizers and significant amounts can enter surface water supplies in run-off from cultivated fields. This can promote excessive growth of algae and other aquatic plants. Ammonia is found in water as NH_3 (its un-ionized form) and as NH_4^+ (its ionized form called ammonium). In water the two forms (NH_3 and NH_4^+) exist in equilibrium and their combined concentration is referred to as total ammonia. This equilibrium is dependent on water pH and temperature, with high pH and temperature causing a shift from NH_4^+ --> NH_3, and low pH and temperature favoring a shift from NH_3 -->NH_4^+. In the presence of sufficient dissolved oxygen, ammonia breaks down to form nitrate and nitrite, two forms of nitrogen that are also readily taken-up by plants. The toxicity of ammonia in surface waters is related to the total amount of ammonia present, and in particular the ratio of NH_3:NH_4^+. Ammonia in domestic drinking water is not a problem for humans, however, temperature and pH dependent Manitoba water quality objectives have been established for fish and other aquatic life.

Arsenic (mg/L) (As^{+3} and As^{+5})

Arsenic is a metalloid (metal-like) element that is sometimes present in surface water in trace amounts. The main source of arsenic in surface water is weathering of igneous and sedimentary rocks that contain arsenic. The amount of arsenic in surface waters varies from place to place in accordance with underlying geological formations. Human sewage, industrial effluents, and pesticide run-off also contribute a significant amount of arsenic to surface waters. Arsenic has a relatively complex chemistry in water. Various forms or compounds of arsenic can be present, with certain forms being more

chemically reactive than others. In large concentrations arsenic can be toxic to plant and animal life. It has been shown to accumulate in certain aquatic organisms, and thus chronic exposure to lower concentrations may also cause problems.

Atrazine (µg/L) ($C_8H_{14}ClN_5$)

Atrazine (2-chloro-4-ethylamino-6-isopropylamino-1,2,3-triazine) is an organonitrogen herbicide used extensively across Canada as a mechanism for pre- and post-emergent weed control, primarily in corn and canola crops. It is further used to control weeds on non-cropland and industrial areas, and has had success in silviculture (forestry) applications. Atrazine is distributed under a number of trade names in Canada, including: Aatrex®; Calmix® 5; Chipman® Atrazine Flowable; Co-op® Atrazine 90W Herbicide; Niagara® Liquid Atrazine; Primextra®; Shell® Atrazine 90W; and Shell® Blazine Liquid Herbicide. Atrazine enters the aquatic environment through production, accidental spillage, use, and disposal. It has been estimated that approximately 1% of the atrazine applied to agricultural land enters nearby surface water supplies as a result of field run-off. Atrazine is removed from water via microbial and chemical degradation. Little information is available with regard to the role of water chemistry in the breakdown of this herbicide and the rate at that it occurs. Atrazine has been classified as being potentially carcinogenic to humans.

Boron (mg/L) (B)

Boron is a metalloid (metal-like) element essential, in trace amounts, for flower and fruit development, and hormone movement in plants. It is presently not considered a necessary element in the diet of humans. Weathering of igneous and sedimentary rocks, and leaching of soil all contribute boron to surface waters. Boron has a wide variety of uses in the chemical industry. Perhaps most notably, it is an ingredient in borax, a domestic and industrial cleaning compound and water softener, and as such can readily be passed into surface waters through effluent drainage. Boron occurs in water as the borate ion ($B(OH)4^-$) and as weak boric acid salt (H_3BO_3). However, because boric acid has low solubility in water, the tendency for disassociation is also low and free boron ions (B^{+3}) are rare. Boron toxicity can occur at high concentrations, leading to diarrhea, headaches,-vomiting, kidney problems, and possibly sterility. Boron concentrations in surface waters in Canada generally fall below 0.5 mg/L.

Bromoxynil (µg/L) ($C_7H_3Br_2NO$)

Bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) is the common name for a group of phenoxy-acid herbicides containing bromine. It is one of the most commonly used herbicides on the Canadian prairies. It is used for the control of broad-leaved vegetation in grain crops. Bromoxynil is also often used in combination with other herbicides such as MCPA, diclo-methyl, and dicamba. The types of bromoxynil herbicides used in Canada tend to adhere strongly to soil and vegetation particles, thus limiting leaching and run-off into ground or surface waters. Bromoxynil can, however, enter surface waters through accidental spills, improper disposal and clean-up, and aerial spray drift. Bromoxynil herbicides appear to be broken down quite rapidly in water. The rate of degradation is dependent on water pH, temperature, and exposure to sunlight. Research has demonstrated that the herbicide has moderately high acutely toxic effects on the liver, but has not been shown to be carcinogenic in animals. Activated charcoal filtration appears to be effective in removing bromoxynil from drinking water.

Cadmium (mg/L) (Cd^{+2})

Cadmium is a metallic element found in small amounts in the earth's crust; usually associated with zinc, lead, and copper ores. Cadmium has a number of industrial applications such as metal plating, and is an important ingredient in nickel-cadmium storage batteries, solders, and electrical equipment Pathways into surface water include weathering of cadmium containing igneous rocks and shales, emissions and effluent from the mining industry, run-off from agricultural lands (found in some pesticides), and the burning of fossil fuels. In general only trace amounts (< 0.001 mg/L) of cadmium

are found in surface water supplies. The form, chemistry, and solubility of cadmium in surface water is complex and is influenced by pH, hardness (calcium and magnesium), and the presence of other metal ions. Food is the main source of cadmium intake by humans. Chronic long-term exposure to cadmium can cause gastrointestinal problems, bone deterioration, and kidney disease. There have been no concrete links made between cancer in humans and cadmium consumption, however, research into this area continues. Because cadmium is found in food, it is important to minimize the amount ingested through drinking water, and thus minimize the total cadmium in one's diet.

Calcium (mg/L) (Ca^{+2})

Calcium is often the most abundant dissolved element in surface water supplies. This is due to its abundance on the earth's surface (it is a major constituent of limestone rock) and the fact that it is readily dissolved from rocks and leached from the soil by water. Calcium is essential for bone growth and maintenance in vertebrates and cell wall and cell membrane structure in plants. When dissolved in water calcium exists as the calcium ion (Ca^{+2}). This calcium ion is strongly electropositive and easily attracts negatively charged ions to form salt compounds (e.g.: calcium carbonate $CaCO_3$) that precipitate out of solution. This activity is enhanced by high water temperatures. Thus, in most instances the concentration of calcium ions in solution tends to decrease during the summer and increase in the fall and winter. Levels of calcium in surface waters of western Canada range from 0.28 to 67.0 mg/L. There is no established guideline or water quality objective for maximum acceptable calcium concentration in human drinking water. The only guideline at present is for livestock and is established at 1000 mg/L. High levels of calcium, in company with magnesium, contribute to increased hardness of the water and high pH values.

Carbon, Total (mg/L) (C)

Carbon is the most common element in all living organisms. Along with hydrogen and oxygen it forms carbohydrates (sugars, starch, cellulose) that account for up to 96% of the dried weight of plant material. Total carbon is the sum of all inorganic and organic forms of carbon in the water. Carbon sources in water include decaying plant and animal material, effluent from industry, human sewage, agricultural run-off, weathering of carbonate rock, plant and animal respiration, and gas exchange with the atmosphere. Presently there are no guidelines or objectives for total carbon in surface water.

Carbon, Total Inorganic (mg/L) (C)

Total inorganic carbon (TIC) is a measure of the amount of carbon present in inorganic compounds in water. Some of the major inorganic carbon compounds in water include carbonates (e.g.: calcium carbonate - $CaCO_3$), bicarbonates (e.g.: sodium bicarbonate $NaHCO_3$), and carbonic acid (H_2C0_3). These inorganic carbon compounds usually dissolve quite readily in water and have a strong influence on water hardness, pH, and alkalinity. Sources of inorganic carbon include weathering of limestone and dolomite rock that contain magnesium and calcium carbonates, and carbon dioxide from respiring organisms and the atmosphere. Presently there are no guidelines or objectives for TIC in surface water.

Carbon, Total Organic (mg/L) (C)

Total organic carbon (TOC) refers to the amount of carbon in organic material in the water, and as such is an overall indicator of the organic content of the water. TOC can occur in both dissolved and particulate forms. The main sources of TOC in surface waters are photosynthesis and decaying plant and animal tissue. Domestic sewage, effluent from certain industries (e.g.: pulp and paper), and agricultural run-off can also contribute organic carbon to surface waters. Concentrations of TOC in water are affected by shoreline erosion, plant productivity, and the specific composition of the organic material (the amount of carbon depending on the type of material present). At present there are no guidelines or objectives for TOC in surface water. However, steps should be taken to reduce levels as much as

possible as the amount of TOC in water has a direct effect on the amount of oxygen in the water. Dissolved oxygen is consumed as organic material is decomposed. Thus, water high in TOC concentrations can become anaerobic (oxygen depleted), that can affect fish and other aquatic organisms, as well as create taste and odour problems. Artificial aeration of the water can help to alleviate this problem. High organic carbon concentrations have also been linked to increased formation of trihalomethanes in water disinfected with chlorine.

Chloride (mg/L) (Cl^-)

Chloride is the negatively charged ion of chlorine. Chlorine is an essential element for both animal and plant life. In combination with positively charged ions, chloride forms such salts as sodium chloride (common table salt), potassium chloride (potash), and calcium chloride (road salt). The relatively high water solubility of chloride salts make them important and useful substances for the chemical and agricultural industry. Concentrations of chloride in surface waters are usually <10 mg/L under natural conditions. However, chlorides usually increase with the use of chlorine as a disinfectant or bleaching agent, and with the use of water softening salts. As well, saline groundwater intrusion may occur in certain areas. High chloride levels in drinking water are not considered a health concern, but may result in taste problems and can adversely affect sensitive aquatic plant species.

Chromium (mg/L) (Cr^{+6} (hexavalent chromium or chromium (VI)))

Chromium is a white, lustrous, hard metal that is very resistant to corrosion. This makes it very useful as a protective and decorative coating for other metals such as brass, bronze, and steel. It is also used extensively in the production of paints, dyes, explosives, ceramics, and paper, and in some fertilizers and pesticides. Major pathways for chromium into surface water include the weathering of chromium minerals such as chromite ($FeCr_2O_2$), and industrial emissions. Chromium can exist in a number of ionic states in water, but chromium (III) (trivalent chromium - Cr^{+3}) and chromium (VI) (hexavalent chromium - Cr^{+6}) are the most common. Chromium (III) is actually considered an essential element for protein, sugar, and lipid metabolism in humans and other animals. Because of this it is considered non-toxic, but can, in water, be converted to the toxic chromium (VI), if the water is chlorinated. Research has yet to show a clear link between cancer and chromium intake. However, prolonged exposure to chromium (VI) can cause gastrointestinal, liver, and kidney problems. Laboratory analysis is concerned with determining the concentration of chromium(VI) because it is the toxic form of the element in water. Concentrations in Canadian surface waters are generally low; ranging from <0.001 to 0.044 mg/L for total chromium, and <0.001 to 0.023 mg/L for chromium (VI).

Coliform Bacteria, Fecal (fecal coliform units/100 ml)

Fecal coliforms are a group of bacteria comprised of *Escherichia coli* (more commonly referred to as *E. coli)* and species of the genus *Klebsiella*. Both *E. coli* and *Klebsiella* spp. occur naturally in the intestinal tract of birds and mammals. *Klebsiella* spp. may also be found in organic-rich effluents such as those from pulp and paper operations. Fecal coliforms are important because they can indicate the presence of other disease-producing organisms. High numbers of fecal coliform bacteria in water generally indicates the presence of undisinfected fecal matter. Sources of fecal coliform bacteria include feces from humans, livestock, and wildlife. The presence of fecal coliform bacteria is considered unacceptable in drinking water. As with total coliforms, fecal coliform levels in drinking water can usually be controlled by disinfection methods. Lab results of <10/100 ml indicate that there were probably fecal coliforms were found in the water samples.

Colour (True Colour Units)

The primary concern for colour in drinking water is one of aesthetics. Colour itself is not harmful, but high values are considered aesthetically unpleasant, and are indicative of excessive levels of organic matter and/or metals (e.g. iron, manganese, and copper).

Conductivity (µS/cm)

Conductivity is an indirect measure of the dissolved salt or mineral content in the water. Conductivity is measured by passing an electrical current through the sample. The higher the concentration of dissolved materials in the water, the higher the electrical conductivity. Thus, conductivity is very low in distilled water, and high in saline, alkaline, and hard water. There are presently no domestic consumption guidelines or objectives for conductivity.

Copper (mg/L) (Cu^{+2})

Copper is a metallic element that can occur in nature in pure form, but is more often found associated with other metals in mineral complexes. It is an essential element for certain enzymatic processes in plants and animals. Copper is used extensively in the production of electrical wire, piping, and numerous metal alloys. It is also an important constituent in pesticides used to protect and preserve wood and to control algae and other plant growth in water supplies used for drinking. Weathering of rocks and minerals, corrosion of brass and copper pipes, run-off from cultivated fields, the use of copper compounds as algaecides, and sewage plant and mining effluents are the most common pathways for copper into surface water supplies. In non-polluted surface waters in Canada copper concentrations rarely exceed 0.05 mg/L. The chemistry of copper in water is very complex and not fully understood. Generally if present in water it is as the cupric ion (Cu^{+2}). However, the concentration of these ions is strongly influenced by water pH. At pH levels above 6.5, cupric ions tend to precipitate out of solution as $Cu(OH)_2$ or combine with carbonates, oxides, and sulphides to form colloidal suspensions or precipitates. High concentrations of copper can lead to corrosion of zinc and aluminum, staining of laundry and bathroom fixtures, and may impart a bitter taste to drinking water. Copper is toxic to humans only at very high concentrations.

2,4-D (µg/L) ($C_8H_6Cl_2O_3$)

2,4-D ((2,4-dichlorophenoxy)acetic acid) is a phenoxy-acid herbicide used to control broadleaf weeds on cultivated land, pasture land, lawns, right-of-ways, and industrial property. It is also used in forestry to suppress the growth of undesired hardwood species and, in doing so, promotes the growth of conifers. 2,4-D has the same chemical formula as dicamba (another phenoxy-acid herbicide), but possesses a different molecular structure. There a large number of registered herbicide in that 2,4-D is an active ingredient. Some examples include Agrotect®, Aqua-Kleen®, Dacamine®, Esteron®, Killex®, Weedar®, and Weedone®. Agricultural run-off, aerial drift, direct application (to control vegetation along ditches and roadsides), accidental spills, indirect applications (i.e. over-spray of adjacent water bodies), and urban sewage are major sources of 2,4-D in surface waters. The herbicide has been detected at concentrations below 30 µg/L (0.030 mg/L) in raw and treated drinking water supplies across the country. 2,4-D in water is degraded through hydrolysis (decomposition through interaction with water molecules), photolysis (exposure to sunlight and ultraviolet radiation), and microbial activity. Such factors as dissolved oxygen content (the higher the better), pH, clarity, and temperature of the water influence the rate of degradation of the herbicide. Current research has indicated that 2,4-D may be a carcinogen (cancer causing agent) in animals.

Dicamba (µg/L) (C8H6Cl203)

Dicamba (3,6-dichloro-o-anisic acid) is a widely used phenoxy-acid herbicide. Dicamba has the same chemical formula as 2,4-D (another phenoxy-acid herbicide), but the molecular structure of the two herbicides differs. Dicamba is a broad spectrum herbicide used for control of broadleaf weeds and woody perennials. In Canada pesticides containing dicamba are increasingly being used with other herbicides, such as bromoxynil and 2,4-D, for vegetation control in croplands, pastures, roadsides and right-of-ways, and forest plantations. Dicamba is sold as a liquid, but is also available in pellets and granules. In Canada it is sold under the trade names Banvel® Herbicide, Banvel® 720 Herbicide, and Dycleer® Herbicide. It is also an ingredient in Killex®, that is used extensively on lawns. Dicamba can

enter surface waters through spills, aerial drift, improper disposal methods, and direct overspray of water bodies during application. Dicamba is very soluble in water and run-off from adjacent cropland is another pathway into the aquatic environment. Microbial degradation is the major way in that dicamba is broken down in water. Studies have shown that the half-life (time required for the concentration to be reduced by half) of dicamba in water is less than a week, but may vary depending on the various chemical and biological characteristics of the water body. Dicamba is a fairly low acute liver toxin. Granular activated charcoal is a potential method of removing dicamba from drinking water.

Hardness (mg/L)

Hardness is a measure of the positively charged ions dissolved in water. Calcium (Ca^{+2}) and magnesium (Mg^{+2}) are the main contributors to water hardness because of their high concentrations in nature. High hardness values result from water draining through carbonate rock and other calcareous materials that are high in calcium and magnesium. Water with hardness levels ranging from 0 to 30 mg/L is considered soft, while levels in excess of 180 mg/L are characteristic of very hard water. Hardness influences the form and toxicity of some heavy metals. Hard water can be treated with a softener, but this will result in elevated chloride and sodium or potassium levels in the water. A domestic surface water quality objective of 200 mg/L has been recommended in Manitoba based on aesthetic considerations. No other guidelines or objectives have been proposed.

Iron (mg/L) (Fe^{+2}, Fe^{+3})

Iron is the fourth most common element in the earth's crust. It is a heavy metal that is essential for photosynthesis in plants and production of hemoglobin in red blood cells of humans. Iron is naturally released to surface waters through weathering of iron bearing minerals, but significant amounts are also released through industrial processes, corrosion of iron and steel, and discharges from mining operations. Iron concentrations in freshwater on the Canadian prairies can range as high as 14 mg/L. This, however, is rare. Levels of iron in water above 0.3 mg/L can lead to staining of laundry and plumbing fixtures, while higher concentrations can impart a metallic taste and yellow precipitate in the water. If concentrations exceed 0.5 mg/L it may interfere with zeolite water softening. Excessive levels of iron in water may also indicate environmental stresses such as acidification and anaerobic conditions (i.e. lack of oxygen).

Lead (mg/L) (Pb)

Lead is a common heavy metal found in the earth's crust. It is found in at least 200 different minerals, most of that are rare, with the exception being the mineral galena. Lead is used in the production of storage batteries and is an important ingredient in the manufacture of numerous chemical compounds used in a variety of industries. Weathering of minerals containing lead is the main natural pathway for entering surface waters. Significant amounts of lead are also released in metal smelting emissions, and mine and industrial effluents. The North American ban on lead based additives to automotive fuel has eliminated the formerly high emissions from automobile exhaust. Levels of dissolved lead in natural surface waters are generally quite low (0.001 - 0.050 mg/L in Canadian waters). The chemistry of lead in the aquatic environment is relatively complex and not fully understood. Lead tends to bind with organic material to form soluble, colloidal (suspended), and particulate compounds. Dissolved oxygen, hardness, pH, and the concentration and composition of inorganic and organic matter all appear to affect the concentration of lead in surface water. Lead is bioaccumulated (stored in tissues and organs) by plants and animals, and can have toxic effects on organisms that experience prolonged exposure; even at low concentrations. The Health Canada maximum acceptable concentration guideline for lead in drinking water is 0.010 mg/L. This guideline is based on long-term exposure and concentrations slightly or periodically above the guideline may not necessarily pose a health risk.

Lindane (µg/L) ($C_6H_6Cl_6$)

Lindane (γ-isomer of 1,2,3,4,5,6-hexachlorocylohexane) is used for insect control in agricultural and silvicultural applications and in dips, dusts, and sprays for livestock and pets. Like most pesticides, lindane can enter the aquatic environment through run-off from cultivated land, accidental spillage, aerial drift, unintentional overspray of adjacent water bodies, poor disposal and equipment cleaning techniques, and urban sewage. Most studies indicate that lindane is relatively stable in the water column. However, in biologically active aquatic environments lindane can be biologically transformed with half lives of several days to more than a year. Lindane may be bioaccumulated in aquatic organisms. In high enough concentrations, lindane can be toxic to fish as well as insects including bees.

Magnesium (mg/L) (Mg^{+2})

Like calcium, magnesium is an abundant element in surface water supplies. Weathering of igneous and sedimentary rock (e.g. dolomite), in that it is a common constituent, are the main natural sources of magnesium in surface waters. Significant contributions to surface waters can also originate via effluent from chemical and textile manufacturers, tanneries, and cement plants. Magnesium is an essential element for enzymatic activity and protein synthesis in plants and animals. It is also an important component of chlorophyll in plants. Levels of magnesium in surface waters of western Canada range from 0.03 to 168.0 mg/L. There are no drinking water guidelines for magnesium. However, along with calcium, it is a major contributor to water hardness. Water with high levels of magnesium (>150 mg/ml) can have taste problems, and prolonged consumption may cause diarrhea.

Manganese (mg/L) (Mn^{+2})

Manganese is a heavy metal that is essential, in trace amounts, for the normal growth and development of plant and animal life. Natural sources of manganese in water result from weathering of mineral deposits, where it is often associated with iron. As such, manganese levels in surface waters are usually closely correlated with iron levels. High levels of manganese in drinking water result in taste problems, staining of plumbing fixtures, and may promote the growth of certain micro-organisms in treatment systems. Manganese is usually present in surface waters at concentrations less than 1.0 mg/L.

MCPA (µg/L) (C9H9ClO3)

MCPA ((4-chloro-2-methylphenoxy)-acetic acid) is a hormone-type phenoxy-acid herbicide used to control broadleaf weeds in cereal crops, pasture land, and lawn turf. Trade names for MCPA include Weedar® MCPA Concentrate, Brominal® Plus, Rhomene®, Rhonox®, and Chiptox®. Like most herbicides, MCPA can enter the aquatic environment through run-off from cultivated land, accidental spillage, aerial drift, unintentional overspray of adjacent water bodies, poor disposal and equipment cleaning techniques, and urban sewage. Dissipation in water is by photolysis (exposure to sunlight and ultraviolet radiation) and microbial degradation, and can be complete in 14 to 32 days. Little has been published regarding the toxicity of MCPA to humans and livestock. However, studies on long-term exposure point to kidney dysfunction as the main toxic effect on laboratory animals. There is also some suspicion that MCPA has an indirect carcinogenic effect on the liver. In light of this, a guideline for MCPA concentration in domestic water supplies is being developed.

Nickel (mg/L) (Ni^{+2})

Nickel is the 23rd most abundant element in the earth's crust. It is commonly found in mineral deposits in association with antimony, arsenic, and sulphur. Nickel is a very important economic metal since it is used in the production of storage batteries, coins, and stainless steel and other corrosion resistant metal alloys. The majority of nickel production comes from sulphide minerals such as pentlandite ($(FeNi)_9S_8$). Large pentlandite deposits are found near Sudbury, Ontario, making it one of the largest nickel producing regions in the world. Nickel enters surface water primarily through weathering of rocks and minerals, the burning of fossil fuels, and in mining wastewater. The occurrence

of nickel in water results from the disassociation of soluble nickel salts. Nickel can occur in a number of ionic forms in water, but the most common form is as Ni^{+2}. Nickel can also combine with or become adsorbed to carbonates, iron and manganese oxides, silica, suspended particulate matter, and organic material in water. The solubility of nickel in water is influenced by pH and hardness. Generally pH values above 6.0 result in reduced concentrations of nickel in the water column. Concentrations of nickel in non-polluted surface waters in Canada are usually around 0.001 to 0.002 mg/L. However, nickel is bioaccumulated by some aquatic plants and animals, including fish. The guideline for nickel in human drinking water is currently under review by Health Canada.

Nitrate-Nitrite (mg/L) (NO_3^-, NO_2^-)

Nitrate (NO_3^-) and nitrite (NO_2^-) are two inorganic forms of nitrogen found in surface water. Along with ammonia, they are a very important source of nitrogen for aquatic plants. Nitrates are used extensively as an ingredient in nitrogen fertilizers. Thus, water run-off from cultivated land is a major source of nitrates in surface waters. Nitrates can also be added to surface waters through the decomposition of plant material and animal wastes, and leachate from igneous rocks. Generally nitrate levels in surface waters in western Canada rarely exceed 5 mg/L, and are usually below 1 mg/L. Nitrite is also found in surface waters, but usually at levels much lower than nitrate. Nitrite concentrations in natural settings are usually around 0.001 mg/L. Sources of nitrite include industrial effluents and animal waste. High levels of nitrates-nitrites in municipal or farm water supplies in rural Manitoba are usually a sign of poor sewage treatment and/or run-off from cultivated land (excessive crop fertilization) and feedlots/pastures. The maximum acceptable drinking water guideline set by Health Canada is 10.0 mg/L for nitrate (reported as nitrogen) and 1.0 mg/L for nitrite (reported as nitrogen). In combination (nitrate-nitrite reported as nitrogen) the concentration should not exceed 10 mg/L. Concentrations of nitrate-nitrite (as nitrogen) above 10.0 mg/L may result in 'blue baby' condition (methemoglobinemia) in infants, which, under certain conditions and prolonged exposure, can be fatal.

Nitrogen - Total Kjeldahl (mg/L) (N in organic compounds and NH_3)

Kjeldahl (pronounced 'kell-dall') nitrogen is a measure of the sum of organic nitrogen and ammonia in a water body. By subtracting the amount of ammonia in the water one can calculate the amount of nitrogen that is bound up in organic molecules in live and dead aquatic organisms. Thus, total Kjeldahl nitrogen (minus ammonia) is indicative of the amount of biological productivity in a surface water supply. A maximum acceptable concentration guideline for total Kjeldahl nitrogen has not been set, however, guidelines are available for the inorganic forms of nitrogen; namely ammonia, nitrate, and nitrite.

Oxygen (mg/L) (O_2)

Oxygen, a gaseous element, is a requisite for most life on earth. Exceptions include a number of anaerobic bacteria species that are adapted to living in oxygen depleted habitats. Elemental oxygen is very reactive, and oxygen gas itself is composed of two tightly bound oxygen atoms (O_2). Sources of dissolved oxygen include the atmosphere and plant photosynthesis. Oxygen is moderately soluble in water and temperature, salinity, turbulence (mixing), and elevation (atmospheric pressure variations) affect its solubility. Solubility decreases as temperature, salinity, and elevation increase, and turbulence decreases. Decomposition of plant and animal material by bacteria and plant and animal respiration use up large quantities of dissolved oxygen. If inputs of oxygen are not kept in balance with oxygen consumption rates, then anaerobic (oxygen depleted) conditions may result. This can create odour and taste problems and affect the overall chemistry of the water body. There is no guideline or objective for oxygen in human or livestock drinking water or in irrigation water. However, to avoid anaerobic conditions and support aquatic life, it is recommended that oxygen levels be maintained between 5.0 and 9.5 mg/L (or 47 - 60% saturation depending on temperature). In the case of dugouts, this can usually be achieved through artificial aeration.

pH (pH units)

Water pH is a measure of the concentration of hydrogen ions (H^+) in the water. The concentration of H^+ in water determines the water's acidity. The pH is measured on a negative logarithm scale from 0 - 14. Therefore, the lower the pH value for a water sample, the higher the concentration of H+ and the more acidic the water. A value of 7 pH units is neutral, while those above 7 are basic (i.e. alkaline). Knowledge of pH is important as it influences the concentration of a number of trace metals and the productivity of aquatic organisms. As well, chlorination of water for disinfecting purposes is less successful if pH is above 8.5. The pH can vary throughout the year, and guidelines and objectives are shown as ranges. Maintenance of pH within the guideline and objective ranges should be an important goal for all surface water supplies.

Phosphorus, Total (mg/L) (P in a variety of inorganic and organic forms)

Phosphorus is an essential mineral nutrient for plant and animal life. In both cases it is a component of adenosine triphosphate (ATP), the molecule used in the storage and transfer of energy in living organisms. It is also important in the maintenance and growth of bone and teeth in humans. In aquatic settings it is often the nutrient that is most important in determining the overall productivity of the ecosystem. Phosphorus is a very reactive element and in nature always exists with other elements to form organic or inorganic compounds. The total phosphorus in water is a summation of dissolved forms, forms adsorbed to sediment particles, and compounds contained in the cell walls of aquatic plants and animals. Phosphorus compounds are released into surface water through weathering of soil and rock and the decomposition of organic material. Domestic and industrial sewage and run-off from fertilized cultivated lands and livestock areas also contribute significantly to the total phosphorus in surface waters. However, because it is rapidly taken-up and assimilated by organisms, phosphorus concentrations under natural conditions tend to be low. High concentrations of phosphorus have not been shown to be toxic to humans. However, in combination with other factors, high levels of phosphorus can result in excessive algae, fungal, and macrophyte (aquatic weeds) growth. Total phosphorus levels below 0.025 mg/L in Lake, ponds, and reservoirs, and less than 0.05 mg/L in rivers and streams usually do not result in excessive algae or macrophyte growth.

Phosphorus, Dissolved (mg/L) ($H_2P0_4^-$, $HP0_4^{-2}$, $P0_4^{-3}$)

The dissolved phosphorus content of water refers to that portion of the total phosphorus content that is present in the water after filtration (0.45 microns). Generally these are phosphate ions that are not bound to suspended particulate matter or tied-up in living organisms. The most common ionic forms of phosphate found in water include phosphate ($P0_4^{-3}$), dihydrogen phosphate ($H_2P0_4^-$), and monohydrogen phosphate ($HP0_4^{-2}$). It is these forms, often referred to as orthophosphates, that are available for up-take by plants. The concentration of dissolved phosphate ions in water is influenced by pH; the activities of fungi, bacteria, algae, and invertebrates; and the concentration and composition of trace metals, organic compounds, and other particulate matter in water.

Potassium (mg/L) (K^+)

Potassium is a major mineral element common in clay and sedimentary shales. Along with nitrogen and phosphorus, it is one of the most important plant nutrients. It is essential for enzyme activity and the maintenance of turgor pressure, without that plants develop weak stem and root systems. It is also necessary for proper osmotic balance and nerve function in higher animals. Most potassium in surface waters originates from leaching and weathering of soils that release potassium salts. Potassium salts are generally very soluble in the aquatic environment, therefore potassium is found mainly in its ionic form (K^+) in water. Concentrations of potassium in surface waters rarely exceed 20 mg/L, although ranges as high as 33.0 mg/L have been recorded in western Canada. There are no maximum

acceptable guidelines or objectives for potassium in surface water supplies. Although one is very unlikely to encounter it in a natural setting, levels above 2000 mg/L can be toxic to humans.

Simazine (µg/L) ($C_7H_{12}ClN_5$)

Simazine (2-chloro-4,6-bis(ethylamino)-s-triazine) is an organonitrogen herbicide used extensively across Canada as a mechanism for control of annual grasses and broad leaf weeds, primarily in corn, established alfalfa, orchards and for weed control in drainage ditches. Simazine is distributed under a number of trade names in Canada, including: Simazine Atanor®; Simazol®; Princep®; Caliber®90; Gesatop®; Primatrol S®; Drexel® Simazine; Simanex®; Sim-Trol®; and Nezitec®. Simazine enters the aquatic environment through production, accidental spillage, use, and disposal. Simazine is removed from water via microbial and chemical degradation. Simazine can persist in flooded soils for up to three years. Simazine in the presence of intermediary nitrate has been classified as being potentially carcinogenic to humans.

Sodium (mg/L) (Na^+)

Sodium is the sixth most common element in the earth's crust. Sodium is essential for nerve function and water balance in higher animals, but is usually a deterrent to proper growth and development in plants. Weathering of salt rock deposits is the main natural source of sodium in surface water. Concentrations in surface waters, therefore, can vary greatly geographically because of spatial variation in mineral deposits. Prolonged exposure to concentrations above the guideline and objective can be a factor in kidney, circulatory, and heart diseases in humans. Consultation with a physician is recommended for those on restricted sodium diets whose drinking water approaches or surpasses the guideline or objective. It should be noted that some water softeners, used to reduce water hardness, will increase the levels of sodium in drinking water.

Sulphate (mg/L) (SO_4^{-2})

Sulphate is a negatively charged ion composed of one atom of sulphur and four atoms of oxygen. Sulphur, in low concentrations, is an essential element for plant and animal life. It is through the intake of the sulphate ion that plants obtain their sulphur requirement. Sulphate is second only to the carbonate ion (CO_3^-) (see alkalinity) in abundance in surface waters. It originates from sedimentary rocks such as shale, as well as from industrial effluents and mine drainage wastes. The use of blue-stone (copper sulphate) for algae control can also lead to increased levels of sulphate in water. Excessive sulphate levels can have a laxative effect on consumers.

Total Dissolved Solids (mg/L)

Total dissolved solids is a measure of the filterable salts and minerals in a water sample. High total dissolved solids concentrations usually result in poor taste and may, if high enough and depending on the composition, become a health concern. Total dissolved solids may consist of a single dominant solute (salt or mineral) or a large number of different solutes salts depending on the water source.

Total Suspended Solids (mg/L)

Total suspended solids is the non-filterable residue in a water sample. As the name implies, it refers to suspended rather than dissolved particles, and includes clay, silt, large inorganic and organic molecules, and even small aquatic plants and animals. Land run-off and algal blooms are major contributors to the level of total suspended solids in surface waters. High levels of total suspended solids in a water body result in a lower degree of light penetration. This may be advantageous in that it leads to a decline in algae and weed growth. However, it can lead to problems with water intake filters, decrease the success of chlorination, and reduce suitability for desirable aquatic organisms. There are no guidelines for total suspended solids surface water supplies, however, an objective of 25 mg/L has been set by Manitoba Environment for the protection of aquatic life.

Trifluralin (µg/L) ($C_{13}H_{16}F_3N_3O_4$)

Trifluralin (a,a,a-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine) is an organonitrogen-based, fluorine containing, pre-emergence herbicide used for control of broadleaf weeds and grasses in a number of cereal, grain, and vegetable crops. In Canada it is sold in large amounts under a number of trade names, including Treflan®, Triflurex®, Rival®, and Fortress®. Trifluralin is a very volatile herbicide in that it evaporates easily into the air following application. It has a relatively low solubility in water. Thus, transport in run-off water from cultivated land into adjacent surface water supplies is usually minimal. As such, pathways into the aquatic environment tend to be via accidental spills, improper disposal, cleaning of equipment, aerial drift, and accidental over-spray of adjacent water bodies during application. Once in water, trifluralin is broken down by sunlight, degraded by microbial activity, and lost to the atmosphere through volatilization. The rate of dissipation in water is not known, but is likely dependent on temperature, exposure to sunlight, and water clarity factors such as turbidity, colour, and organic matter content. Tests have shown that trifluralin in water can be removed by reverse osmosis, granular activated charcoal, and alum treatment of the water body. The acute toxicity of trifluralin is low, but chronic (prolonged or constant) ingestion can cause weight loss, increased liver size, and kidney problems. Health Canada has established interim guidelines for trifluralin in water. These may be altered once investigations into the possible carcinogenic properties of the herbicide have been conducted.

Turbidity (NTU)

Turbidity is a measure of light penetration through the water column. As such, it is directly related to total suspended solids, and is often used to indicate overall water clarity. Water turbidity is an important consideration in the design of drinking water treatment systems since the success of disinfecting by chlorination is related to the amount of suspended solids in the water. In the case of high turbidity values, water treatment systems have to be designed to remove suspended particles from the water prior to chlorination, otherwise chlorination is unsuccessful and/or trihalomethanes can be produced.

Zinc (mg/L) (Zn^{+2})

Zinc is a heavy metal that is necessary in trace amounts for plant and animal life. In animals it is involved in the activities of digestion enzymes, while in plants it is an important element in chloroplast and hormone production. Zinc is the 24th most abundant element in the earth's crust. It is found mainly in sulphide, carbonate, and silicate minerals. Sulphide minerals containing zinc (e.g. zinc blende (ZnS)) are generally associated with iron, copper, and lead deposits, and zinc production is a by-product of mining for these elements. Zinc is used as a protective coating for iron and steel and as a component in numerous metal alloys such as brass (with copper) and bronze (with copper and tin). Zinc enters the aquatic environment through weathering of minerals and rocks, and through mining waste, sewage, and landfills. In water it exists in many suspended and dissolved forms; from simple ions (Zn^{+2}) through to complexes in that it is bound to clay and organic particles and colloids. Overall concentrations of zinc in water tend to be relatively low, and in non-polluted surface waters rarely exceed 0.10 mg/L in Canada. Some zinc does find its way into drinking water because of the use of zinc in plumbing materials. The major source of zinc in the human diet is through food. Ingestion of zinc higher than the recommended daily requirement of 4 - 10 mg has no adverse affect on health. However, excessive concentrations of zinc in drinking water can cause taste problems.

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